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PREFACE.

THE present volume contains eighteen papers, three of which were published under the auspices of Joint Research Committees of the Institute and the British Iron and Steel Research Association, which were presented at the Autumn Meeting of the Institute held in London on November 22nd and 23rd, 1945, and also the discussion and correspondence on them. Eleven papers (six of them Joint Committee papers) to be included in the programme of papers for the Annual General Meeting in May, 1946, had been set in type in the present format before the decision to enlarge the size of the *Journal* had been taken, and accordingly are also included in this book; correspondence on these papers will be found in the No. I. volume of the *Journal* for 1946.

The foregoing papers, together with the Minutes of Proceedings of the Meeting and biographical notes on deceased Members, comprise Section I. of this *Journal*.

Section II. is devoted to a survey of the literature of the manufacture and properties of iron and steel, and kindred subjects, and consists of a collection of abstracts of articles from the Transactions and Proceedings of scientific societies and from the technical press. This Section also contains reviews of recent books and bibliographies of literature dealing with the manufacture and properties of iron and steel. The matter included in this Section has already appeared in the *Bulletin of The Iron and Steel Institute*, which is issued monthly.

In front of the title-page are inserted lists of Bibliographies and Special Reports issued by the Institute, together with a list of Translations made available from December 1st, 1945, to June 30th, 1946.

4, GROSVENOR GARDENS,

LONDON, S.W. 1.

20th July, 1946.

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ABBREVIATIONS AND SYMBOLS.

Å.	Ångstrom	unit(s) = 1×10^{-10} m.	kX.	crystal Ångstrom(s) = 1000 Siegbahn X-units.
A.C.	air-cooled; alternating current.		lb.	pound(s).
A.H.	air-hardened.		L.F.	low-frequency.
amp.	ampere(s).		M	molar (solution).
amp.hr.	ampere-hour(s).		m.	metre(s).
approx.	approximately.		m.amp.	milliampere(s).
at.-%	atomic per cent.		max.	maximum.
at.wt.	atomic weight.		mg.	milligramme(s).
atm.	atmosphere(s) (pressure).		min.	minimum; minute(s).
A.W.G.	American wire-gauge.		ml.	millilitre(s).
Bé.	Baumé (scale).		mm.	millimetre(s).
b.h.p.	brake horse-power.		m.m.f.	magnetomotive force.
B. & S.	Brown and Sharpe (gauge).		m.p.	melting point.
B.o.T.	Board of Trade.		mV.	millivolt(s).
b.p.	boiling point.		mμ	millimicron = 1×10^{-9} m. = 10 Å.
B.T.U.	Board of Trade unit(s).		N.	normal (solution).
B.Th.U.	British thermal unit(s).		N.T.P.	normal temperature and pressure.
B.W.G.	Birmingham wire-gauge.		O.H.	open-hearth; oil-hardened.
C.	centigrade (scale).		O.Q.	oil-quenched.
cal.	calory (-ies).		oz.	ounce(s).
c.c.	cubic centimetre(s).		p.d.	potential difference.
c.d.	current density.		pH	hydrogen-ion concentration.
c.g.s.	centimetre-gramme-second unit(s).		p.p.m.	parts per million.
cm.	centimetre(s).		r.p.m.	revolutions per minute.
coeff.	coefficient(s).		sec.	second(s).
conc.	concentrated.		sp.gr.	specific gravity.
const.	constant(s).		sq.	square.
cu.	cubic.		S.W.G.	standard wire-gauge.
cwt.	hundredweight(s).		T.	tempered.
D.C.	direct current.		temp.	temperature.
dia.	diameter.		V.	volt(s).
dil.	dilute.		VA.	volt-ampere(s).
dm.	decimetre(s).		W.	watt(s).
e.m.f.	electromotive force.		Wh.	watt-hour(s).
e.v.	electron volt(s).		W.G.	water-gauge.
F.	Fahrenheit (scale).		W.Q.	water-quenched.
ft.	foot, feet.		wt.	weight.
ft.lb.	foot-pound(s).		wt.-%	weight per cent.
g.	gramme(s).		yd.	yard(s).
gal.	gallon(s).		γ	microgramme(s) = 1×10^{-6} g.
H.F.	high-frequency.		μ	micron(s) = 1×10^{-6} m.
h.p.	horse-power.		μμ	1 millionth micron = 1×10^{-12} m. = 0.01 Å.
h.p.hr.	horse-power-hour(s).		Ω	ohm(s).
hr.	hour(s).		°	degree (arc or temperature).
in.	inch(es).		'	minute of arc; foot (feet).
in.lb.	inch-pound(s).		"	second of arc; inch(es).
I.S.W.G.	Imperial standard wire-gauge.		<	less than.
K.	absolute temperature (Kelvin scale).		>	greater than.
kg.	kilogramme(s).		≧	not less than.
kg.cal.	kilogramme-calory(-ies).		≡	not greater than.
kg.m.	kilogramme-metre(s).		≡	equal to or less than.
km.	kilometre(s).		≡	equal to or greater than.
kV.	kilovolt(s).		≠	not equal to.
kVA.	kilovolt-ampere(s).		≡	identically equal to.
kW.	kilowatt(s).		≈	approximately equal to.
kWh.	kilowatt-hour(s).		∝	proportional to.

MINUTES OF PROCEEDINGS

PAPERS AND DISCUSSIONS

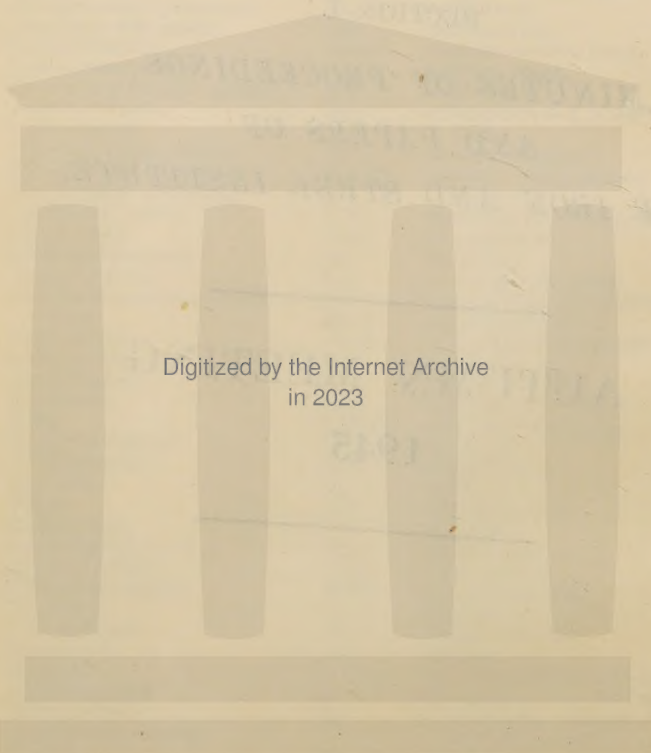
AUTUMN MEETING IN LONDON, 1945.

SECTION I.

*MINUTES OF PROCEEDINGS
AND PAPERS OF
THE IRON AND STEEL INSTITUTE.*

AUTUMN MEETING

1945



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MINUTES OF PROCEEDINGS

AND

PAPERS AND DISCUSSIONS

AT THE

AUTUMN MEETING IN LONDON, 1945.

THE AUTUMN MEETING OF THE IRON AND STEEL INSTITUTE was held at the Offices of The Chartered Surveyors' Institution, 12, Great George Street, London, S.W.1, on Thursday and Friday, November 22 and 23, 1945, the PRESIDENT (Mr. Arthur Dorman) being in the Chair. There were three sessions, at 10.30 a.m. and 2.30 p.m. on Thursday and at 10 a.m. on Friday.

The Minutes of the previous Meeting were taken as read and signed.

OBITUARY.

The PRESIDENT (Mr. Arthur Dorman) : It is my sad duty to report the death of Sir Allan Macdiarmid, who was a President of the British Iron and Steel Federation, and of Mr. James Henderson, the previous President of this Institute, who died two days ago. Sir Allan Macdiarmid always inspired quiet confidence. He was a great friend of many of us, and a leader in the industry. His brain and initiative brought into being the big new works at Corby, and he did yeoman work as President of the British Iron and Steel Federation at one of the most difficult periods in the history of the steel industry. He was doing that work when he was taken away from us in the middle of the year.

We all knew Mr. James Henderson, a successful President of this Institute, who had been all his life in the steel trade, and who was one of the founders of the great Appleby-Frodingham works. He had held many high positions in the industry. We shall miss him very much, and I think it will be your wish that our expression of condolence be sent to Mrs. Henderson.

The Members stood in silence for a few moments as a tribute of respect.

CHANGES ON THE COUNCIL.

President-Elect for 1946.

The PRESIDENT : I have to announce that the Council have nominated Dr. C. H. Desch, F.R.S., to be the next President of the Institute, to take office in May of next year. (*Applause.*) I am very glad to hear that applause, because it coincides with my own feelings. We are going to have an excellent President, and I am very glad that Dr. Desch has seen his way to accept office.

Vice-Presidents and Members of Council.

The SECRETARY (Mr. K. Headlam-Morley) : I have to announce the following changes on the Council. Mr. R. Mather becomes a Vice-President, and Mr. R. A. Hacking has been elected a Member of Council. Dr. C. F. Goodeve, O.B.E., F.R.S., has been elected an Honorary Member of

Council. In addition, Dr. J. W. Donaldson and Mr. J. H. Patchett are nominated Honorary Members of Council in succession to Provost J. Tennent and Mr. L. Wright during their periods of office as Presidents of the West of Scotland Iron and Steel Institute and the Cleveland Institution of Engineers.

In accordance with Bye-Law No. 10, the following Vice-Presidents and Members of Council will retire in rotation at the next Annual General Meeting, and will be eligible for re-election :

Vice-Presidents.—Mr. J. R. Menzies-Wilson, Mr. C. E. Lloyd and Sir William Larke, K.B.E.

Members of Council.—Professor J. H. Andrew, Mr. W. B. Baxter, Mr. Gerald Steel, Mr. W. J. Dawson and Mr. I. F. L. Elliot.

OPENING REMARKS BY THE PRESIDENT.

The PRESIDENT: First of all, I should like to welcome our visitors from overseas. It is pleasant to see that we have quite a number here. After so many years' absence, it is encouraging to us to feel that they still take an interest in the Institute, and we hope and believe that the happy relations which we have always had with our friends in the same industry overseas will be maintained and extended.

I am very glad that Dr. Goodeve has been elected an Honorary Member of Council. He is the new Director of the British Iron and Steel Research Association, and it augurs well for the relations between that body and the Institute in the future.

Dr. Desch and the Secretary have visited France, and the Secretary has paid a visit to Sweden in the last few months. Dr. Griffiths, the President of the Institute of Metals and an Honorary Member of our Council, is just back from America, and he was at our Council meeting yesterday. We asked him to approach our American friends to see what prospects there were of them paying us a visit not next year (I do not think that is possible) but the year after. We shall hear more of that in the future, but it is impossible at the moment to make any final plans for 1947.

This is the first meeting since the war in the East came to an end, and naturally, at the end of six years of war, our thoughts go to the Members and friends who are no longer with us. We are still suffering from the aftermath of war, and that is likely to continue for some time. I think that to-day's meeting, in the circumstances, is very creditable.

We are full of confidence for the future. We shall have Dr. Desch as our President next year, and that in itself augurs well. Our membership is bigger than it has ever been before; it has increased by 12% during the war, and the upward movement is still continuing.

We have kept in close touch with the new British Iron and Steel Research Association, and we are sure that it will operate to our mutual advantage, as also will the arrangements for closer working with the Institute of Metals, to which I have referred on previous occasions.

When controls on paper and printing are removed we intend to expand our publications and produce them in a form which we hope will be more convenient to Members. We propose to work with the Research Association to improve the service of the Library and Information Departments.

Affiliation with Local Societies.

Next I want to report affiliation with local societies. Yesterday the Council accepted an application for affiliation from the Cleveland Institution of Engineers. That is a body which I think is about six years

older than this Institute. We have already similar arrangements with the Lincolnshire Iron and Steel Institute, with the Sheffield Society of Engineers and Metallurgists, with the Staffordshire Iron and Steel Institute, which I believe claims to be the oldest of them all, and with the Swansea and District Metallurgical Society.

The object of these arrangements is to secure facilities for our Members to meet and discuss subjects of technical interest in the districts. We think that this can be done better by friendly working arrangements with well-established local societies, and the essence of our proposal is that the independence of the affiliated local societies shall be maintained. There is no intention of having anything except an arrangement to try to work together more closely than in the past. Publications come into it. There are one or two points under discussion which have not been settled, but there is, I repeat, no intention to interfere with the independence of any of the affiliated local societies.

Education.

I have referred on previous occasions to the formation of the Institution of Metallurgists. We think that all metallurgists should seek to join this professional body in the class of Fellow, Associate, or Licentiate, according to their qualifications. Connected with that is the step which we have taken, in conjunction with this new Institution, the Institute of Metals, and the Institution of Mining and Metallurgy to form a Joint Committee on Metallurgical Education. I feel confident that you will hear more of this development in the future. Progress has been made in connection with the National Certificates in Metallurgy, to which I have referred before, and quite a number of technical colleges are running courses which we hope will be approved. We regard this Joint Committee as a very important function of the Institute, and we want your help.

Carnegie Scholarships.

We are the trustees of substantial sums of money from which the Carnegie Scholarships can be awarded. Relatively few grants have been made during the war, and it may be a little premature to say much about the matter, but we are accumulating funds, and the Council are willing to consider applications for grants from research workers of universities and works on technical as well as scientific subjects. Normally a single grant will not exceed £250.

WILLIAMS PRIZE.

The PRESIDENT: At the Annual General Meeting this year I announced that the Council had awarded a Williams Prize to Mr. R. W. Evans, of Messrs. Guest Keen Baldwins Iron and Steel Co., Ltd., for his paper on "The Heating of Open-Hearth Furnaces with Mixed Coke-Oven and Blast-Furnace Gas." It is a very good practical paper, of exactly the type that we want, and we are very grateful to him for presenting it. Mr. Evans was unable to attend the last meeting, but I am glad to see him here to-day and have much pleasure in presenting him with his Diploma.

The President then, amid applause, handed the Diploma to Mr. Evans.

ELECTION OF Dr. ANDREW CLASEN AS HONORARY MEMBER.

The PRESIDENT: The Council decided yesterday to add another to our small number of Honorary Members—we have only five or six—and

we decided to invite His Excellency the Minister for Luxemburg, Dr. Andrew Clasen, who I am sorry is unable to be here to-day, to be an Honorary Member of the Institute. (*Applause.*) We all knew and liked his father, and we like the son too. We have happy recollections of our visit to Luxemburg before the war, and we wish that country well. Dr. Clasen is a young man. Sometimes our Honorary Members are old, but we thought that we would make a change, and demonstrate that youth is not necessarily a bar to Honorary Membership of the Institute.

It was agreed, at the suggestion of the President, to send to Mr. W. J. Dawson, a Member of Council, who had been seriously ill, a message of good wishes and sincere hope for his speedy recovery.

BALLOT FOR THE ELECTION OF MEMBERS AND ASSOCIATES.

Mr. E. M. SUMMERS (Melton Mowbray, Leics.) and Mr. R. SHARP* (Stanton-by-Dale, Nottingham), who had been appointed scrutineers of the ballot, reported that the following sixty-five candidates for membership and thirty-three for associateship had been duly elected :

MEMBERS.

Adam, *Second Lieut.* François M. M. (Frenois, Belgium). **Barlow**, Maurice William (Wincobank, Sheffield). **Bayliss**, Ernest George, B.Sc. (Lond.) (Witton, Birmingham). **Beardshaw**, Bennett (Sheffield). **Bird**, Stanley (Middlesbrough). **Blyth**, Howard Neville, B.A. (Hons.) (Oxon.) (Bath). **Bradley**, A. J., D.Sc., Ph.D., F.R.S. (Sheffield). **Brooks**, William Barker (Pittsburgh, Pa., U.S.A.). **Bucknall**, Eric H., M.Sc. (Birmingham). **Cochenet**, André Jean Charles (London). **Cockey**, James Edward Lewis, A.M.I.Mech.E. (London). **Curphey**, John Stanley (Middlesbrough). **Damien**, René (Denain, France). **Davies**, William, Ph.D., M.Sc. (Sheffield). **Dreyer**, Jan C. (Vereeniging, S. Africa). **Echevarria**, Arturo de (Bilbao, Spain). **Elliott**, Bernard (Sheffield). **Emmerich**, Liberata, B.A., B.S. (Pennsylvania, Pa., U.S.A.). **Evans**, Howard, A.Met. (Sheffield) (Birmingham). **Frapwell**, Stanley Arthur, B.Sc. (Hons. Lond.), A.R.I.C. (Ruislip, Middlesex). **Freeman**, Major Henry George (Sheffield). **Friedmann**, Paul (London). **Geib**, Maurice (Denain, France). **Ghosh**, S. N. (Jamshedpur, India). **Gibbs**, C. H. (Sheffield). **Grainger**, Leslie H. (Billingham-on-Tees, Co. Durham). **Green**, Frederick Hoyland (Sheffield). **Hamilton**, Frank Alexander, B.E., F.S.A.S.M. (Waratah, N.S.W., Australia). **Hindley**, William Norman, B.Sc. (Hons.), Ph.D., A.R.I.C. (Woolwich). **Hope**, Dennis Francis (Newport, Shropshire). **Jones**, John Paul Phillips (London). **Jones**, Leslie, M.Sc., B.Sc., F.R.I.C. (Slough, Bucks.). **Karim**, Abdul, M.Sc. (Moghalpura, India). **Kidd**, Thomas Robinson (Birmingham). **Lahr**, *Tech. Sgt.* Robert William (U.S. Army). **Langton**, L. R. (Karabuk, Turkey). **Leake**, Robert (Scunthorpe, Lincs.). **Leschen**, John G. (Boston, Mass., U.S.A.). **Lloyd**, Michael Charles (Wincobank, Sheffield). **Lumsden**, Quentin (London). **McCallum**, *Lieut.-Col.* N. M. R., B.Sc. (Hons. Eng.) (Lond.), A.M.I.Mech.E. (London). **Matthews**, John Ambrose, A.M.I.Mech.E., M.I.Mar.E., M.Inst.F., M.Inst.W. (London). **Mitchell**, Robert Morton (London). **Morton**, *Chief Petty Officer* George Reginald (Worthy Down, Hants.). **Painter**, Ralph Arthur (Hereford). **Powell**, Thomas, A.Met. (Sheffield) (Wincobank, Sheffield). **Pugh**, Walter, A.Met. (Sheffield) (Cardiff). **Rutherford**, Lancelot (London). **Sanderson**, Tom, B.Sc.Tech., A.R.I.C. (Stocksbridge, Sheffield). **Scholten**, Willem, D.Sc. (The Hague, Holland). **Searly**, Arnold, A.Met. (Sheffield) (Sheffield). **Shaw**, John, B.Sc. (Lond.) (Sheffield). **Smith**, Stanley James (Lye, Worcs.). **Smith**, Stanley Livingstone, D.Sc. (London). **Thomas**, Richard John (Pontardulais, Swansea). **Turnbull**, John Gordon Muirhead, B.Sc. (Hons.) (Lond.), A.R.I.C. (Newcastle-on-Tyne). **Tuzcu**, Ziyat (Karabuk, Turkey). **Valyi**, Emery I., D.Sc. (New York, N.Y., U.S.A.). **Wakker**, Charles H., D.Sc. (Geneva, Switzerland). **Ward**, Edward Denis, M.A. (Cantab.) (Farnborough, Hants.). **Willis**, Arthur Tom (Sheffield). **Wilshaw**, Cecil T. (London). **Wolf**, Walter Albert Louis, B.Sc. (Hons.), A.M.I.C.E. (Middlesbrough). **Woodcock**, William (Sheffield). **Yorke**, Alfred Charles (London).

ASSOCIATES.

Adlington, Alan Geoffrey (Swansea). **Allen**, Peter Joseph (Witton, Birmingham). **Arabacioglu**, Sezai (Sheffield). **Bowen**, Kevin William Joseph, B.Sc. (Billingham). **Brasunas**, Anton de Sales (Columbus, Ohio, U.S.A.). **Brittain**, Philip Ian (Weybridge, Surrey). **Child**, Henry Cave (Glasgow). **Collinge**, John Duncan Chisholm (Bradford). **Cunniffe**, Peter William Arthur (Briton Ferry, Glam.). **Dickie**, James (Stocksbridge, Sheffield). **Gemmell**, Matthew George (Stocksbridge, Sheffield). **Harrison**, Geoffrey Lionel (Coventry). **Hopkins**, Alan David (Cardiff). **Kenyon**, Roy H. (Sheffield). **Kershaw**, Cyril Gordon (Cambridge). **Knapton**, Arthur George (Swansea). **Knights**, Ronald John (London). **Lakin**, John Raymond, B.Sc. (Stocksbridge, Sheffield). **McLeod**, Ian (Sutton, Surrey). **Morgan**, Edward Llewellyn (Willenhall, Staffs.). **Morris**, Anthony Tranter Richard (Coventry). **Muir**, Andrew Douglas (Glasgow). **North**, John Malcolm (Swansea). **Parfrey**, Ewart Harold, B.Sc. (London). **Ruddle**, Ronald Waverley, M.A. (Newport, Mon.). **Sanders**, Maurice Burns (Newport, Mon.). **Siddall**, Reginald Cobden (Sutton-in-Ashfield, Notts.). **Sokell**, Jack (Wombwell, Barnsley). **Spear**, Peter (Sheffield). **Thomas**, Morgan John Alwyn (Briton Ferry, Glam.). **Waple**, Norman Harry (Wolverhampton). **Waters**, Ronald Thomas Frederick (Swansea). **West**, Sidney Boulton (Sketty, Swansea).

PRESENTATION OF PAPERS.

A list of the papers included in the programme of the Meeting will be found in Table I. The following were presented for verbal discussion:

*Thursday, November 22 :**Morning Session :*

"Distribution of Materials in the Blast-Furnace.—Part I."

By H. L. SAUNDERS and R. WILD.

"Sinters and Sintering.—Part I." By H. L. SAUNDERS and H. J. TRESS.

Afternoon Session :

"Dolomite Linings for Basic Electric Arc Furnaces." By E. C. BRAMPTON, H. PARNHAM, and J. WHITE.

"Some Design and Operating Features of a New Blooming Mill." By G. A. V. RUSSELL and G. W. Fox.

*Friday, November 23 :**Morning Session :*

"A Micro-Spectrographic Method for the Quantitative Analysis of Steel Segregates." By J. CONVEY and J. H. OLD-FIELD. (Paper No. 30/1945 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Inclusions Sub-Committee).)

"Sources of Error in Diamond Pyramid Hardness Measurements on Hardened Steel." By W. N. HINDLEY.

"The Determination of Nitrogen in Ferro-Alloys and Other Materials by Direct Nesslerization without Distillation." By W. C. NEWELL. (Paper No. 29/1945 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Sub-Committee on Gaseous and Non-Metallic Inclusions).)

TABLE I.—*Complete List of Papers Presented at the Autumn Meeting, 1945.*

- W. B. ADAM and D. DICKINSON: "The Substitution of Blackplate for Tinplate in Cans for Fruit and Vegetables."
- E. C. BRAMPTON, H. PARNHAM and J. WHITE: "Dolomite Linings for Basic Electric Arc Furnaces."
- J. CONVEY and J. H. OLDFIELD: "A Micro-Spectrographic Method for the Quantitative Analysis of Steel Segregates." (Paper No. 30/1945 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Inclusions Sub-Committee).)
- A. B. EVEREST, J. W. GRANT and H. MORROGH: "The Development of a Single-Blow Impact Test for Cast Iron."
- MARGARET C. M. FARQUHAR, H. LIPSON and ADRIENNE R. WEILL: "An X-ray Study of Iron-Rich Iron-Silicon Alloys."
- ERNEST S. HEDGES and the Staff of the Tin Research Institute (Greenford), and L. A. JORDAN and the Staff of the Paint Research Station (Teddington): "The Use of a Tin Undercoat to Improve the Corrosion Resistance of Painted Steel."
- W. N. HINDLEY: "Sources of Error in Diamond Pyramid Hardness Measurements on Hardened Steel."
- S. T. JAZWINSKI: "The Control of Tropenas-Converter Blowing by a Direct-Vision Spectroscope."
- W. C. NEWELL: "The Determination of Nitrogen in Ferro-Alloys and other Materials by Direct Nesslerisation without Distillation." (Paper No. 29/1945 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Sub-Committee on Gaseous and Non-Metallic Inclusions).)
- T. F. PEARSON: "The Improvement of the Citric-Acid Solubility of Basic Open-Hearth Slags containing Fluorspar."
- W. J. REES: "Mould and Core Paints and Washes, and Parting Powders." (Paper No. 14/1945 of the Steel Castings Research Committee (submitted by the Moulding Materials Sub-Committee).)
- L. REEVE: "The Relation between the Hydrogen Content of Weld Metal and Its Oxygen Content."
- G. A. V. RUSSELL and G. W. FOX: "Some Design and Operating Features of a New Blooming Mill."
- H. L. SAUNDERS and H. J. TRESS: "A Rapid Method of Ore Testing. The 'S.K.' Porosity Test."
- H. L. SAUNDERS and H. J. TRESS: "Sinters and Sintering.—Part I."
- H. L. SAUNDERS and R. WILD: "Distribution of Materials in the Blast-Furnace.—Part I."
- APPENDIX: "A Note on Scale Effect for Falling Particles in Blast-Furnace Models." By O. A. SAUNDERS.
- H. A. SLOMAN, T. E. ROONEY and T. H. SCHOFIELD: "A Preliminary Investigation of the Constitution of Mild-Steel Arc-Weld Deposits."
- J. S. VATCHAGANDHY and G. P. CONTRACTOR: "Analytical Survey of a Rimming-Steel Ingot."

**Papers for the Annual General Meeting, 1946,
included in the Present Volume.**

The Council having decided to enlarge the format of the *Journal* for the No. 1 volume of 1946, it has been necessary to include in the present volume certain papers which had already been set in the old style but which could not be issued in time for inclusion in the programme of the present meeting. These papers are listed in Table II. Any discussion and/or correspondence that may arise on them will be printed in the No. I. volume of the *Journal* for 1946.

TABLE II.—*Papers for the Annual General Meeting, 1946, included in the Present Volume.*

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| <p>THE FOUNDRY PRACTICE SUB-COMMITTEE: "The Manufacture of Some Thin-Walled Steel Castings, With Notes on the Influence of Pouring Speed." (Paper No. 19/1946 of the Steel Castings Research Committee (submitted by the Foundry Practice Sub-Committee).)</p> <p>S. O. AGRELL: "Mineralogical Observations on Some Basic Open-Hearth Slags."</p> <p>C. R. BARBER: "The Design and Performance of Some Commercial Optical Pyrometers of the Disappearing-Filament Type." (Paper No. 18/1946 of the Steel Castings Research Committee (submitted by the Foundry Steel Temperature Sub-Committee).)</p> <p>R. A. CRESSWELL: "The Tinning of Cast Iron."</p> <p>W. DAVIES and W. J. REES: "British Bonding Clays." (Paper No. 17/1946 of the Steel Castings Research Committee (submitted by the Moulding Materials Sub-Committee).)</p> <p>W. DAVIES and W. J. REES: "British Resources of Steel Moulding Sands.—Parts 6 to 10." (Paper No. 16/1945 of the Steel Castings Research Committee (submitted by the Moulding Materials Sub-Committee).)</p> <p>W. DAVIES and W. J. REES: "The Hot-Strength Characteristics of Moulding Sands." (Paper No. 15/1945 of the Steel Castings Research Committee (submitted by the Moulding Materials Sub-Committee).)</p> <p>A. H. JAY and K. W. ANDREWS: "Note on Oxide Systems Pertaining to Steel-Making Furnace Slags."</p> <p>F. LÁSZLÓ: "Tessellated Stresses.—Part IV."</p> <p>K. A. PYEFINCH: "Methods of Assessment of Anti-Fouling Compositions." (Paper No. 16/1946 of the Corrosion Committee (submitted by the Marine Corrosion Sub-Committee).)</p> <p>W. J. WRAŻEJ: "Local Heating in Plain Carbon Steels."</p> |
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THE CONTROL OF TROPENAS-CONVERTER BLOWING BY A DIRECT-VISION SPECTROSCOPE.*

By S. T. JAZWINSKI, DPL. ING. MET.
(K. & L. STEELFOUNDERS AND ENGINEERS, LTD., LETCHWORTH).

(Figs. 2 to 6 = Plate I.)

SYNOPSIS.

The development of a converter flame during the blow and the appearance and disappearance of certain lines of the spectrum observed through the direct-vision spectroscope are described. No attempt was made in these preliminary investigations to measure the wave-lengths of the bands, only their relative positions being recorded.

A very faint continuous spectrum appeared at the beginning of the blow and grew stronger as the flame became brighter. The most pronounced yellow band appeared when boiling began; when ejects ceased a green band, faint at first, appeared. During the carbon flame two other green bands and two red bands became visible. At times a blue band was discernible. When all bands disappeared the wind was shut off.

The real value of this lies in the possibility of controlling the converter blow without introducing the human factor, and the consequent elimination of over- and under-blown heats. The disappearance of the red, green, and yellow bands is an indication that the blow is finished and the carbon near 0.1%. If the wind is not shut off when the bands disappear, the heat becomes overblown, with consequent low carbon content, higher losses of metal due to oxidation, and excessive wear on the lining.

The conclusions point to a very definite relationship between the bands in the flame spectrum and the composition of the metal in the bath. This leads directly to the application of the "electric eye" to the Tropenas converter to attempt a more rigid control of the process.

INTRODUCTION.

THE essential function of the converter in a steel foundry is to produce a bath of liquid metal at a suitable temperature which can subsequently be alloyed to the desired composition and can be easily cast. The oxidation of silicon, manganese, and carbon during the blow takes place approximately as shown in Fig. 1. Point *E* is the so-called "end of the blow," *i.e.*, the point at which the wind should be shut off. An earlier shut-off results in underblown steel with high percentages of impurities, while a later shut-off results in overblown metal. As neither underblowing nor overblowing is desirable for producing a steel consistent with strict chemical and mechanical specifications, the end of the blow must be accurately determined.

Although the photo-electric cell has been applied in some modern

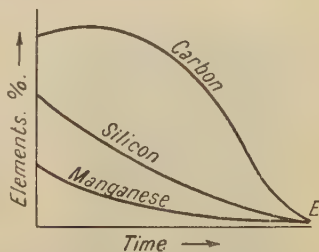


FIG. 1.—Oxidation of Elements in the Converter.

plants to indicate this important end of the blow, the unaided human eye is still the means most widely used.

After observing over a period of time the appearance and changes of the flame of the converter during the blow, one can recognize the appearance of the "carbon flame"; this is a white, bright, unsteady, and fierce flame appearing nearly at the end of the blow. But one is still not sure of the end of the blow. It is claimed that the experienced human eye can judge the end quite accurately; this is true in most cases, but unfortunately not in all, because occasionally underblown or overblown heats are still made. This points to the need for an investigation by means of the miniature direct-vision spectroscope.

The construction of this miniature spectroscope is simple; it comprises an adjustable slit in the outer tube and a compound direct-vision prism in a sliding tube which can be moved forwards or backwards to focus the spectrum. The spectrum observed is due to gaseous atoms or ions. Atoms are activated by thermal energy and the electrons are partially withdrawn from the attracting nuclei. This means that some energy is lost by the atoms. The value of this change corresponds to emitted light of a definite frequency, which also is characteristic of the atom. As a result the so-called atomic spectrum is produced. In the converter flame the excitation of a few lines of the spectrum is observed. It is, of course, not so pronounced as in the case of electric-arc excitation. By observing this spectrum the disappearance of constituents present in the bath can be demonstrated.

CHANGES IN THE CONVERTER-FLAME SPECTRUM.

A summary of the successive changes in the spectrum with reference to the conditions of flame and sparks during an actual blow is given in Table I.

TABLE I.—*Changes in the Converter-Flame Spectrum during a Blow.*

The figures indicate the number of minutes that had elapsed after the beginning of the blow when a certain band or bands appeared or disappeared.

Exp. No.	Appearance of Yellow Band.	Appearance of Green Bands—		Appearance of Red Bands.	Disappearance of Bands.	Wind Shut off.	Blown Metal, Carbon, %.
		Faint.	Clear.				
1 . .	12	...	37	37	40	40	0.08
2 . .	12	30	32	32	37	37	0.08
3 . .	9.5	33	36	38	43.5	43.5	0.09
4 . .	10.4	24	33	...	40	40	0.08
5 . .	4	23	27.5	27.5	32	32	0.07
6 . .	9	33.5	33.5	35.5	38	38	0.09
7 . .	10	27.5	32	32	39.5	39.5	0.09
8 . .	9	22	28	28	34	34	0.08
9 . .	12	28	39	39	42	43	0.05 *

* Overblown metal.

At the beginning of the blow a very faint continuous spectrum was visible. At this moment the flame was dull red mingled with dense brown fume, and the sparks were ejected in a diverging stream with a number of clusters of scintillating sparks (Fig. 2).

The continuous spectrum became gradually brighter and stronger until the flame appeared more bright with less clusters of sparks and



FIG. 2.—The Start of the Blow.



FIG. 3.—The Boil.

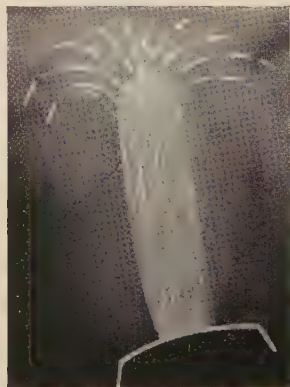


FIG. 4.—After Ejects have Ceased.



FIG. 5.—The Carbon Flame.



FIG. 6.—The Shortened Flame
at the End of the Blow.

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brown fumes. Then ejects were thrown out and a fine, weak, yellow band appeared in the spectrum. The outline of the flame now assumed the shape shown in Fig. 3, which marked the beginning of the boil. Sometimes the ejects continued for several minutes and became very violent. The yellow band was then very clear and steady.

After the ejects had ceased the flame became longer and brighter, with only a few sparks (Fig. 4). At this moment only a yellow band was visible. The flame then dropped and was duller, but it again increased in intensity and brightness. The spectrum now showed the appearance of a green band. At first it was so faint that its appearance was spasmodic. Then the flame became very bright, irregular-shaped and unsteady, with few sparks (Fig. 5); this is the well-known carbon flame. Two other green bands, one on each side of the first one, and two red bands were then visible. Sometimes, if the flame was exceptionally brilliant, a blue band became visible. All these bands then appeared very clear and strong, but after an interval of $\frac{1}{2}$ –1 min. the red, green, and blue bands disappeared and left only the yellow band. At the same time the flame shortened (Fig. 6) and the wind was subsequently shut off.

The relative positions of the bands were as shown in Fig. 7. In these preliminary investigations only the relative positions of these bands were determined; no attempt was made to measure the wave-lengths nor to prove that the yellow band indicated sodium, or the other bands manganese.

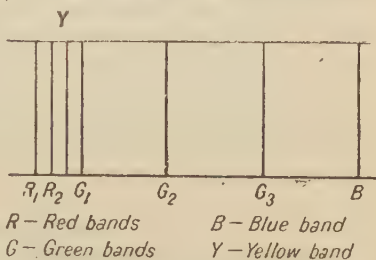


FIG. 7.—Positions of the Coloured Bands in the Spectrum.

DISCUSSION ON THE OBSERVED SPECTRUM CHANGES.

The explanation of the significance of these bands with respect to the extent of the oxidation of impurities in the metal requires more information.

The results for an overblown heat can be summarized as follows :

(1) The temperature of the blown metal will be lower. A rough estimation, based upon the assumptions that the wind is supplied at the rate of 40 cu. ft./sec. and the air finally attains a temperature of 1200° C., has shown that overblowing for one minute will cause a temperature drop of about 70° C. for 2½ tons of metal.

(2) The analysis of the blown metal will show lower percentages of silicon, manganese, and carbon than that of properly blown metal, but, since oxidation after the end of the blow is not very appreciable (see Fig. 1), this difference will be very slight.

(3) Loss of metal will be increased by oxidation of the molten iron.

(4) Excessive wear on the lining can be expected, as the FeO tends to attack the lining and form silicates.

(5) The quantity of slag will be increased.

(6) The FeO content in the slag will be increased.

(7) Difficulty in casting may occur, especially on light and thin-section castings, owing to cold and sluggish metal.

(8) Defective castings may be produced, owing to the oxide inclusions in the molten metal.

Consequently, to prove that the disappearance of red and yellow bands really shows the true end of the blow other investigations must be carried out simultaneously with observations made with the aid of the spectroscope. Only by determining the temperature of the blown metal, the quantity and composition of the slag (before additions), and the metal losses, as well as making the spectroscopic observations, will all the necessary data be obtained.

CONCLUSIONS.

(1) The time interval between the start of the blow and the appearance of the yellow band in the flame spectrum varies. This variation depends upon the temperature of the metal and of the converter lining, *i.e.*, whether they are hot or cold. The appearance of the yellow band is generally accompanied by the commencement of ejection or boiling.

(2) The time interval between the appearance of the yellow band and green and red bands varies. This variation is due to the irregular composition of the metal tapped from the cupola, and the addition of ferro-silicon during the blow.

(3) The first green band always appears before the carbon flame. All the red and green bands are visible while the carbon flame exists.

(4) The end of the blow is reached when the red, green and occasional blue bands *entirely disappear*.

ACKNOWLEDGMENTS.

The author records his thanks to the Directors of K. & L. Steelfounders and Engineers, Ltd., for permission to publish the information included in this paper, and to Mr. T. C. Tsung for his help in experimental work.

CORRESPONDENCE.

Mr. W. M. LORD (The Sandholme Iron Co., Ltd., Todmorden, Lancs.) wrote: I have read this paper with considerable interest and should like to have further details of the construction of the spectroscope used.

The critical period of a blow is, of course, from the time of the appearance of the bushy carbon flame, and the blower has to decide whether to turn the vessel down when the flame begins to drop or at some intermediate time between this point and the final disappearance of the flame at the mouth of the vessel; hesitation can, of course, cause overblowing and all the bad effects associated with it. Any instrument which will assist the blower to decide at exactly which point to turn down his vessel is useful. I am surprised to see that the author suggests that as long a period of blowing as 1 min. can be permitted after the disappearance of the bands, and also that this rather long overblow only causes a reduction of about 0.03% in the blown-metal carbon content.

I hope that the author will proceed with his experiments to correlate the actual spectrum bands with graphical results as obtained by the use of a photo-electric cell, and it would be particularly interesting to know whether the point of the blow when the bands disappear corresponds with one of the points shown on a time/radiant-energy curve as recorded by a photo-electric cell. Jones and Laughlin (British Patent No. 540,243) show on such curves that there are two characteristic humps at the end of a blow, and that their relative positions are related to the FeO content of the metal. It may well be that when the comparison of methods has been made, the author's method of control would be just as efficient for a smaller plant at very much less expense.

AUTHOR'S REPLY.

Mr. JAZWINSKI replied : When the bushy flame, which the steel-maker calls the carbon flame, appears, the actual carbon content in the bath is of the order of 0.5–0.7%. The elimination of carbon proceeds very rapidly until the carbon content is in the vicinity of 0.07–0.1%; thereafter the reaction is slower and the removal of each 0.01% of carbon will need a much bigger proportion of oxygen. As a result, the final steel will be over-oxidized and the heat overblown. The elimination of the traces of carbon is, perhaps, best described as sluggish. This behaviour is similar in other metallurgical steel-melting processes, such as the open-hearth and electric-arc furnaces. It is best shown on a curve plotting the FeO content against the carbon in the liquid bath.

From experience and the analysis of the converter flame, I should say that the vessel should be turned down when the flame begins to drop. In such a case the carbon content of the blown metal will be between 0.09 and 0.12% with a minimum of oxygen which will not have a detrimental effect on the physical properties. I am not suggesting that the heats should be overblown; I am only trying to explain what can happen if the converter heat is overblown, and I did this only to have comparative figures.

With regard to blowing time, I must point out that this is not related at all to the converter capacity but to the converter design. In my case the ratio of bath depth to bath surface area is far from normal, and that explains the long blowing time. On the other hand, in Mr. Lord's case the blowing time of 15 min. is quite normal and this rather suggests that the internal design of his vessel is good. We must distinguish between long blowing time and an overblown heat. In the first case the difference due to a change in practice or converter design will be of the order of a few minutes, and in the latter case $\frac{1}{2}$ min. is sufficient to produce a heat unsatisfactory in some physical properties. So much harm was done to the converter life by overblowing that this process got a bad reputation as a method of making good-quality steel.

With regard to Jones and Laughlin's British Patent No. 540,243 as far as I know the photocell is sensitive to the blue end of the spectrum. In my preliminary experiments I noted more lines, and the calibration of these lines (red, blue and green) together with extensive analyses of steel produced would enable us to answer the question of which line should be selected as indicating the end of the blow. So far, according to this patent, the photocell is sensitive only to a blue line.

NOTE ON OXIDE SYSTEMS PERTAINING TO STEEL-MAKING FURNACE SLAGS.*

FeO-MnO, FeO-MgO, CaO-MnO, MgO-MnO.

By A. H. JAY, Ph.D., M.Sc., F.Inst.P., and K. W. ANDREWS, D.Phil., B.Sc.
(CENTRAL RESEARCH DEPARTMENT, THE UNITED STEEL COMPANIES, LTD., STOCKS-BRIDGE, NEAR SHEFFIELD).

SYNOPSIS.

An X-ray survey has been made of the binary systems FeO-MnO, FeO-MgO, CaO-MnO and MgO-MnO. All systems show complete solubility at a temperature of 1150° C. The variation of lattice spacings with composition in each system is recorded.

THIS work was carried out with the object of explaining more fully the solid-solution effects in two of the primary phases, lime-rich and iron-oxide-rich, found in slowly cooled basic open-hearth slags. Of the four systems named, only two, FeO-MnO and FeO-MgO, have previously been examined and reported in the literature. These particular systems were re-examined to gain experience in this kind of work; to compare the authors' X-ray results with published constitutional data; and to decide, in the case of the system FeO-MnO, on the extent of the supposed two-phase region and to obtain lattice-spacing changes in the single-phase regions.

Preparation of Oxides.

(a) Single Oxides.

The oxides lime, magnesia, ferrous oxide, and manganous oxide were prepared as follows:

Lime	.	.	Calcination of CaCO ₃ at 1000° C.
Magnesia	.	.	A.R. magnesia at 850° C.
Ferrous oxide	.	.	ferrous oxalate <i>in vacuo</i> up to 1050° C. (sample examined by X-rays).
Manganous oxide	.	.	manganous oxalate <i>in vacuo</i> up to 1100° C. (sample examined by X-rays).

(b) Binary Oxide Systems.

The oxide mixtures (0.5 g.) were prepared in the following manner. Weighed amounts of the two oxide powders were mixed together thoroughly in an agate mortar, and the powder was then rammed into a small cylinder. This sample was put into an iron crucible, supported inside a refractory tube which was evacuated to a low pressure. The tube was inserted into a vertical electric furnace; temperatures were taken in the space between the furnace wall and the evacuated tube.

Experiments were conducted to establish the constitution at a temperature of 1150° C. The heating schedule was:

Room temperature to 1350–1370° C. in 2 hr.

Maintained above 1350° C. for 2 hr.

Cooled to 1150° C. in 1 hr.

Maintained at 1150° C. for 1 hr.

Cooled rapidly to room temperature by withdrawal of evacuated tube from furnace.

Visual examination of the samples showed a large volume shrinkage and the absence of contamination from the iron crucible, which had remained free from scale.

*X-Ray Examination.**

The samples were examined in a 9-cm. powder camera. In all cases the oxides had fully reacted with each other, only one phase being found.

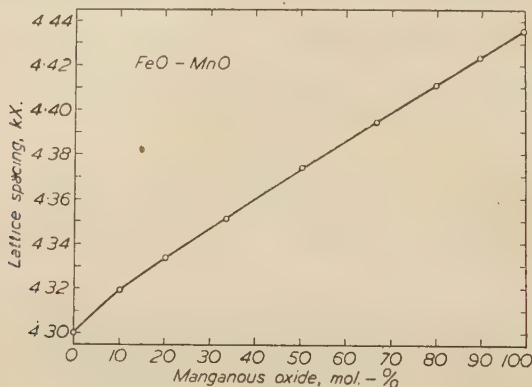


FIG. 1.

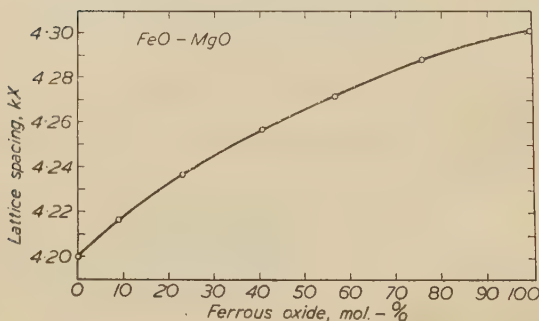


FIG. 2.

FIGS. 1 and 2.—The Relationship between Composition and Lattice Spacings for the Systems FeO-MnO and FeO-MgO.

(1) *System FeO-MnO*¹⁻⁶ in contact with iron, rapidly cooled from 1150° C. (Fig. 1).

Manganous Oxide.		Lattice Spacings, kX. units.
Wt.-%.	Mol.-%.	
0	0	4.300
10	10.1	4.319
20	20.2	4.333 _s
33.3	33.6	4.351
50	50.3	4.374
66.7	66.9	4.394 _s
80	80.2	4.411
90	90.1	4.423 _s
100	100	4.435 _s

* The results have been reported briefly in *Nature*, 1944, vol. 154, p. 116.

These results indicate that in this system there is 100% solubility at temperatures between 1350° and 1150° C. This is in agreement with the work of Herty,² and of Andrew, Maddocks, and Howat,³ and also with more recent work by McCaughey,⁶ but it is in opposition to that of Benedicks and Löfquist,¹ who suggested a two-phase region at 30–60% of MnO, and Hay, Howat, and White,⁴ who suggested one at 45–80% of MnO.

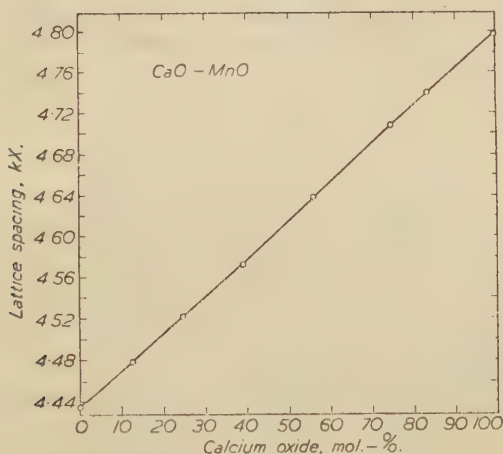


FIG. 3.

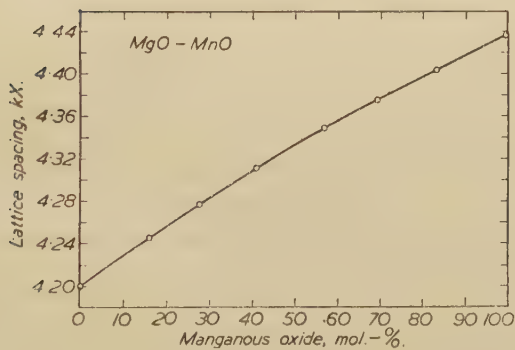


FIG. 4.

FIGS. 3 and 4.—The Relationship between Composition and Lattice Spacings for the Systems CaO-MnO, and MgO-MnO.

The X-ray results give no indication of the presence of a two-phase region at the stated temperatures and full solubility will be accepted in future work.

(2) System $FeO-MgO$ ⁷ in contact with iron, rapidly cooled from 1150° C. (Fig. 2).

Ferrous Oxide.		Lattice Spacings, kX. units.
Wt.-%.	Mol.-%.	
0	0	4.200
15	9	4.216
35	23	4.236
55	40.7	4.256
70	56.8	4.271
85	76.1	4.287 _s
100	100	4.300

The conclusion that there is complete solubility between FeO and MgO is in agreement with the deductions of Bowen and Schairer,⁷ who used thermal and optical methods.

(3) *System CaO-MnO* in contact with iron, rapidly cooled from 1150° C. (Fig. 3).

Calcium Oxide.		Lattice Spacings, kX. units.
Wt.-%.	Mol.-%.	
0	0	4.435 _s
10	12.3	4.479 _s
20	24.1	4.522
33.3	38.6	4.573
50	55.9	4.639
70	74.7	4.710
80	83.5	4.741
100	100	4.798 _s

There is complete solubility between CaO and MnO in the temperature range 1350–1150° C.

There is no literature on this system.

(4) *System MgO-MnO* in contact with iron, rapidly cooled from 1150° C. (Fig. 4).

Manganous Oxide.		Lattice Spacings, kX. units.
Wt.-%.	Mol.-%.	
0	0	4.200
25	15.9	4.244 _s
40	27.5	4.276
55	41	4.310
70	57	4.348
80	69.5	4.375
90	83.5	4.402 _s
100	100	4.435 _s

There is complete solubility between MgO and MnO in the temperature range 1350–1150° C.

There is no literature on this system.

Acknowledgments.

The authors thank the United Steel Companies, Ltd., and the Director of Research for permission to publish this paper.

REFERENCES.

1. BENEDICKS and LÖFQVIST: "Non-Metallic Inclusions in Iron and Steel." London, 1930: Chapman and Hall.
2. HERTY: *Metals and Alloys*, 1930, vol. 1, p. 883.
3. ANDREW, MADDOCKS, and HOWAT: *Journal of The Iron and Steel Institute*, 1931, No. II., p. 283.
4. HAY, HOWAT, and WHITE: *Journal of the West of Scotland Iron and Steel Institute*, 1933–4, vol. 41, p. 97.
5. WHITELEY: *The Iron and Steel Institute*, 1937, *Special Report* No. 16, p. 23.
6. McCaughey: *American Institute of Mining and Metallurgical Engineers, Open-Hearth Proceedings*, 1938, p. 169.
7. BOWEN and SCHAIRER: *American Journal of Science*, 1935, vol. 29, p. 151.

For Correspondence on this Paper see the *Journal*, 1946, No. I.

MINERALOGICAL OBSERVATIONS ON SOME BASIC OPEN-HEARTH SLAGS.*

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(Table II. = Plate II.)

(Figs. 7 to 28 = Plates III. to VI.)

SYNOPSIS.

The principal phases that may occur in basic open-hearth tapping slags are lime, magnesio-wüstite, nagelschmidtite, di- or tricalcium silicate, and apatite, with smaller amounts of monticellite, merwinite, and calcium ferrites. In the melting-down stage monticellite, or more rarely merwinite and wüstite-magnetite solid solutions, predominate in those slags in which no fluorspar has been used; in addition a phase is also recorded the properties of which most closely resemble those of steadite. The chemical composition, optical properties, and mutual relations of the above phases occurring in a number of slags are given, and the variations of phase assemblages from two casts are described in detail.

The variation of phase assemblages of these and other slags is summarized by plotting the different assemblages on the ternary diagram $\text{CaO-P}_2\text{O}_5\text{-SiO}_2$, and it is shown that they fall into definite fields on this diagram. With further study of the phase assemblages of slags the chemical compositions of which are known, this diagram could be amplified so that the phase assemblages of basic slags could be predicted from their chemical compositions.

I.—INTRODUCTION.

WHILE seeking material to illustrate the application of petrological methods to industrial processes for demonstration to honours students in geology, the author found that very little information was available on the mineralogical constitution of slags. As the field was relatively unexplored it was thought worth while to see how far petrological methods might be of value in determining the phase relations in slags, and in seeing how these change during refining.

The metallurgist has in the past studied the constitution of metal samples during refining by chemical and microscopical means. The attention paid to slags has nearly always been scant, however; normally a routine analysis of one or more slag samples has been made, and it is seldom that simultaneous microscopical examination has been made of slag and metal samples. The deficiency is particularly marked in the case of basic open-hearth slags.

The microscopic technique of the petrologist has the advantage that it tells us what phases are present in the slag. It depends essentially on determining the optical properties of the phases and comparing them with the optical properties of known phases. Where a new phase of unknown composition is suspected, this is separated by electromagnetic or centrifuging methods and analysed to provide that correlation of optical properties and chemical constitution which enables the phase to be identified again whenever it occurs. If all slag phases were of single or fixed composition, the work would be relatively straightforward, but it is complicated by the fact that the constitution is seldom fixed; most phases show extensive

* Received June 30, 1945.

ranges of solid solution, or what may be better called "atomic replacement," due essentially to the fact that different atoms of similar radius can occupy similar positions in the crystal structure even though their valency is different. These variations in atomic replacement cause variations in the optical properties, and though it is generally possible to say what a phase is, it is not possible to give its chemical composition with any degree of accuracy until sufficient samples differing in degree of atomic replacement have been analysed and their optical constants determined. Then graphs correlating chemical constitution with optical constants can be prepared over the range of known compositions. This has been done accurately for only a few slag minerals, so that there is extensive preparatory work to be carried out. Once this has been done, however, a microscopical examination can give the composition of a phase showing extensive atomic replacement with a considerable degree of accuracy. Thus we avoid the indirect method of molecular recasting of bulk analyses of a slag which may contain several phases showing extensive atomic replacement.

To anyone studying natural minerals the complexity introduced by solid solution or atomic replacement is a commonplace, but it was not until the ionic radii of the elements were determined that the fundamental control of these substitutions was demonstrated. Table I. gives the ionic radii of

TABLE I.—*Ionic Radii (in Ångstrom Units) of the Commoner Elements Occurring in Basic Open-Hearth Slags. (6-fold co-ordination).*

S ⁻² 1.74
F ⁻¹ 1.33, O ⁻² 1.32
Ca ⁺² 1.06
Mn ⁺² 0.91
Mg ⁺² 0.78, Fe ⁺² 0.83, Ti ⁺³ 0.69, Cr ⁺³ 0.64, Mn ⁺³ 0.70, Fe ⁺³ 0.67, Ti ⁺⁴ 0.64
Al ⁺³ 0.57
Si ⁺⁴ 0.39, P ⁺⁵ 0.35, S ⁺⁶ 0.34, Cr ⁺⁶ 0.35
C ⁺⁴ —0.20

the commoner elements occurring in basic slags; from these it will be seen that elements with similar ionic radii fall into groups within which the valency may differ. It is elements in the same groups which can replace each other extensively in phases in which atomic replacement occurs; some, however, like Al⁺³ and Mn⁺², occupy intermediate positions and can replace elements in the groups both above and below them. When examining slags the possibility of these substitutions must always be borne in mind, as they are responsible for the comparative simplicity of slags at least as far as the number of phases present is concerned; they also immediately suggest in what phase an element occurring, say, only in a small amount, is possibly located.

Microscopic examination can also tell us the order of crystallization of the phases in the slag, and planimetric analysis their amounts; in addition the relations of the phases to each other can often be determined, *i.e.*, whether they are compatible or incompatible, whether they show reaction or eutectic relations, &c.

The petrologist can thus eventually tell a great deal about the constitution of a slag, but his findings depend entirely on the slags being crystalline

TABLE II.—The Optical Properties of Some Phases Occurring in or Related to Those in Basic Open-Hearth Slags.

Mineral Name or (Chemical Name).	Chemical Formula.	Solid Solution.	Crystal System Habit.	Cleavage.	Colour in Thin Section. Pleochroism.	Sp. gr.	Optic Orientation.	Refractive Index.			$(\epsilon - \alpha)$ $\gamma - \alpha$.	Optic Sign. Optic Axial Angle.	Twinning.	Notes.	References to Further Data.
								$\alpha(\lambda)$.	$\beta(\lambda)$.	$\gamma(\lambda)$.					
(Lime).	CaO.	Slight (Mn,Fe,Mg)O.	Cubic, cubo-octa- hedral.	(100) perfect.	Colourless to pale yellow, darker margins.	3.32			1.837					Hydrates rapidly to Ca(OH) ₂ , except where stabilized.	6
Periclase.	MgO.		Cubic, cubo-octa- hedral.	(100) good.	Colourless if pure; (MgFe)O yellow to brown-red.	3.58			1.737					Solid solutions called magnesio- wüstite may take up MnO in any amount and Fe ₂ O ₃ and Al ₂ O ₃ in part.	6, 41
Wüstite.	FeO.		Cubic, octahedral or skeletal.		Black, opaque.				2.32						41
Magnetite.	Fe ₃ O ₄ .		Cubic, octahedral or skeletal.		Black, opaque.									Magnetic, grey-white by vertical reflected light.	
(Calcium hydroxide).	Ca(OH) ₂ .		Hexagonal, tabular.	(0001) perfect.		2.23		1.545		1.574	0.029	Uniaxial —.			6
(Monocalcium ferrite).	CaO.Fe ₂ O ₃ .		Tetragonal or hexa- acicular.		Deep red.		X = c.	2.43 Na * 2.35 Li		2.58 Na 2.47 Li	0.015 Na 0.012 Li	Uniaxial —.		With 10% CaOAl ₂ O ₆ . ω 2.25 Li, ε 2.13 Li.	6, 24, 28
(Dicalcium ferrite).	2CaO.Fe ₂ O ₃ .		System ? granular or acicular.		Yellow-brown X > Y = Z.			2.25 Na 2.20 Li	2.22 Li	2.29 Li	0.009 Li	+ 2V moderate.			6, 24, 28
(Tricalcium ferrite).	3CaO.Fe ₂ O ₃ .		Monoclinic, acicular or prismatic.		Opaque to deep ruby red.		Small extinction angle in some sections + Elongation.	≥ 1.73			0.017 approx.			Metallic, dead black by reflected light.	14, 15
Brownmillerite.	4CaO.Al ₂ O ₃ .Fe ₂ O ₃ .		System ? prismatic.		X yellow-brown. Z brown.	3.77	Very small extinction angle.	1.98 Na 1.96 Li	2.05 Na 2.01 Li	2.08 Na 2.04 Li	0.010 Na 0.008 Li	— 2V moderate.	Occasional multiple twin- ning.		6, 23, 24
Larnite. (α-Dicalcium silicate).	α-2CaO.SiO ₂ (Ca ₂ SiO ₄).	Up to 10% of 3CaO.P ₂ O ₅ . Slight with mon- ticellite.	Monoclinic ?	(100) fair.	Colourless to pale green or pale buff.	3.27	Opt.Ax.Pl. ⊥ 010. Z = b. X ^ c = 14-18° in section || 010.	1.705 1.707	1.720 1.715	1.737 1.730	0.022 0.023	+ 2V large. + 2V large.	Lamellar on 100.		6, 24, 42
			Triclinic ? prismatic or rounded.	Prismatic.			Opt.Ax.Pl. ⊥ cleavage. Bxa || cleavage, and bisects obtuse angle between twin lamellae.	1.719		1.733	0.014	+ 2V = 33°.	Two sets of lamellae inter- secting at 54° in sections ⊥ to Y.		13, 12
								1.708		1.735	0.027	+ 2V = 0-10°		From inversion of C ₂ MS ₂ .	26
								1.703		1.713			Max. P-Si substitution.		42
(β-Dicalcium silicate).	β-2CaO.SiO ₂ (Ca ₂ SiO ₄).	Up to 10% of 3CaO.P ₂ O ₅ . ? Negligible with monticellite.	Orthorhombic ? pris- matic, granular.	(010) > (100)	Colourless to pale green or buff.	3.28	Opt.Ax.Pl. || 100. X = c.	1.717		1.735	0.018	+ 2V large.	Lamellar, but rare.		6, 24
							Opt.Ax.Pl. ⊥ best cleav- age. X ^ twin plane = 6-10° in sections ⊥ to Bxa.	1.717		1.736	0.019	+ 2V = 73°.	Lamellar, common also in pseudo-hexagonal groups with Z in direction of twin axis and X ^ X' = 60°.		12
(γ-Dicalcium silicate).	γ-2CaO.SiO ₂ (Ca ₂ SiO ₄).		Monoclinic, prismatic.	(010)	Colourless.	2.94	Opt.Ax.Pl. ⊥ 010. Z = c or Z ^ c = 3°.	1.642	1.645	1.654	0.012	— 2V = 60°.	Lamellar, not common.		6, 24
Rankinite.	3CaO.2SiO ₂ (Ca ₃ Si ₂ O ₇).		Monoclinic, granular to tabular.	(100) ?	Colourless.		— Elongation. X ^ edge of (001) = 15° in section || (010). B = b.	1.641 1.641	1.645 1.644	1.650 1.650	0.009	+ 2V large. + 2V = 64°.			6, 35
(Tricalcium silicate).	3CaO.SiO ₂ (Ca ₃ SiO ₄).		Rhombohedral, tabular.	(0001) poor.	Colourless to pale yellow or olive green.		+ Elongation.	1.719	Nm 1.715	1.724	0.005	Uniaxial —.			6, 13, 24
Monticellite.	CaO.MgO.SiO ₂ (CaMgSiO ₄).		Orthorhombic, prismatic.	(010) poor.	Colourless.	3.2	Opt.Ax.Pl. || 001. X = b.	1.639 1.663	1.646 1.674	1.653 1.680	0.014 0.018	+ 2V = 85° — 2V = 75°.		With 16% (MgFe) ₂ SiO ₄ .	5, 6
Iron monticellite.	CaO.FeO.SiO ₂ (CaFeSiO ₄).		Orthorhombic, prismatic.	(010) poor.	Pale yellow.		Opt.Ax.Pl. || 001. X = b.	1.696	1.734	1.743	0.047	— 2V = 48°.	In monticellites and olivines. P-Si substitution common.		6, 27
Glaucochroite or Man- ganese monticellite.	CaO.MnO.SiO ₂ (CaMnSiO ₄).		Orthorhombic, prismatic.	(010) poor.	Colourless.	3.41	Opt.Ax.Pl. || 001. X = b.	1.679	1.716	1.729	0.050	— 2V = 60°.		CMS, CFS, CMnS all show ex- tensive solid solution with olivines (R ₂ SiO ₄), where R = Fe, Mn, Mg.	5
Merwinite.	3CaO.MgO.2SiO ₂ (Ca ₃ Mg(SiO ₃) ₂).	? slight with Ca ₂ SiO ₄ .	Monoclinic, pris- matic or granular.	(010)	Colourless.	3.15	X ^ c = 36°. Z = b and bisects obtuse angle between twin lamellae.	1.708 1.708 1.711	1.711 1.714	1.718 1.725 1.729	0.010 0.017 0.018	+ 2V = 66° + 2V = 69°.	Polysynthetic with two sets of lamellae intersecting at 42°, one set dominant.		5, 25, 26, 42
Silicocarnotite.	5CaO.P ₂ O ₅ .SiO ₂ .	Partial with 3CaO.P ₂ O ₅ .	Monoclinic, pseudo- hexagonal, granu- lar, tabular.		X Colourless. Y Pale blue. Z Sky blue.			1.632	1.636	1.640	0.008	— 2V large.			2, 17, 22, 29, 30
Nagelschmidtite.	7CaO.P ₂ O ₅ .2SiO ₂ .	Partial with Ca ₂ SiO ₄ .	Granular to tabular.	(001) good. (110) fair.	Colourless or pale buff.	3.035	Bxa ⊥ 001.	1.652 1.680		1.661 1.690	0.009 0.010	+ 2V = 0-20°.		For J2, this paper. With max. substitution P for Si.	2, 31
Steadite.	3(3CaO.P ₂ O ₅).CaO.2CaO.SiO ₂ .		Hexagonal, acicular or prismatic.	(0001) fair.	Very pale buff to brown. X pale brown or brown. Z colourless or pale brown.		— Elongation.		Nm 1.65 1.67		0.003 0.004	Uniaxial —.	Occasional cross-hatched twinning.		16, 19
Thomasite.	6CaO.P ₂ O ₅ .SiO ₂ .2FeO.SiO ₂ .		Hexagonal, acicular, prismatic.		? Blue-green.									No optical data available.	
Fluorapatite.	Ca ₃ (PO ₄) ₂ .CaF ₂ .		Hexagonal, acicular.		Colourless.	3.2	— Elongation.	1.629		1.632	0.003	Uniaxial —.	Occasional cross-hatched twinning.		5, 6, 18
Hilgenstockite (Tetracalcium phosphate).	4CaO.P ₂ O ₅ .		Orthorhombic or monoclinic. Tabular on 010.	(010) poor. (100) poor. (001) poor.	Colourless to pale yellow.	3.06	Opt.Ax.Pl. 010. Z nearly || to c. (Extinction on twin plane = 18°.)	1.650 1.643	1.651	1.656 1.647	0.006 0.004	+ 2V = 30° 20° ed. 40° blue.	Lamellar twinning common on 100 and 001.		6, 19, 32, 33
(α-Tricalcium phosphate).	α-3CaO.P ₂ O ₅ .	Partial with silico- carnotite.		None ?	Colourless.		Nearly straight extinction on twin planes.	1.588		1.591 1.615	0.003	+ 2E = 75°.	Narrow twin lamellae in two sets at 90°.	With max. Si-P substitution.	32
Whitlockite (β-Tricalcium phosphate).	β-3CaO.P ₂ O ₅ .	Partial with silico- carnotite.	Rhombohedral.		Colourless.	3.12-3.19		1.620 1.626		1.623 1.629	0.003 0.003	Uniaxial —.			32, 34

Abbreviations Used in the Table and Elsewhere in the Paper.

a, b, c = crystallographic axes.
α, β, γ = refractive indices for biaxial crystals; γ - α = birefringence, Nm = mean refractive
index, Opt.Ax.Pl. = Optic axial plane, Bxa = Acute bisectrix, + 2V = positive optic axial
angle when Z = Bxa, - 2V = negative optic axial angle when X = Bxa.
X, Y, Z are used to indicate the vibration directions of the fast, intermediate, and slow rays
in biaxial crystals corresponding respectively to the refractive indices α, β, and γ.

ω, ε = Refractive index of the ordinary and extraordinary rays respectively in uniaxial crystals,
ω - ε = birefringence, uniaxial- = uniaxial negative crystal when ω slow, uniaxial+ = uni-
axial + crystal when ω fast.
X, Z are used to indicate the vibration directions of the fast and slow rays in uniaxial crystals
corresponding to either the refractive index ω or ε.

— Elongation = negative elongation when fast ray is parallel or nearly so to crystallographic
elongation.
+ Elongation = positive elongation when slow ray is parallel or nearly so to crystallographic
elongation.
Na or Li following a refractive index determination indicates that it was made with mono-
chromatic sodium yellow or lithium red light.

and the crystals being of a size such that they are amenable to microscopic examination. If they are too small, other techniques have to be employed; for example, examination by means of X-rays, using a comparative powder-photograph technique such as has been successfully applied to the study of refractories.

A review of the literature reveals a lack of information: the majority of the few papers available on slags give no optical properties of the phases identified, or, where they are given for a phase which may show extensive atomic replacement, no chemical analysis of the phase is given.

To economize space and to avoid repetition of recent surveys, a comprehensive review of data from the literature on the constitution of slags is not given. For our purpose reference to the recent papers of White,¹ Barrett and McCaughey,² Trömel,³ Bredig,⁴ and Mason⁴² is sufficient, as these contain excellent summaries of the available information. For the present purpose it is probably of more value to refer to the literature in which we find accurate descriptions of the optical properties of phases known to occur in basic slags and the techniques used in their identification.

General works of reference describing the optical properties of natural and artificial compounds have been published by Winchell^{5, 6} and Larsen and Berman.⁷ Table II. summarizes some of this information and gives references to papers in which optical properties of the common slag-forming minerals are described. For the optical methods used in their study reference should be made to the works of the following: Dana,⁸ Rogers and Kerr,⁹ Hartshorne and Stuart,¹⁰ Johansen,¹¹ and Winchell.^{5, 6}

II.—THE GENERAL MINERALOGY OF BASIC OPEN-HEARTH SLAGS.

Through the courtesy of the Lancashire Steel Corporation, the author was enabled to examine a large number of samples, all of basic open-hearth slags, collected from the slag dumps at Irlam; material from several furnace casts was also sampled in order to see what changes occurred in the mineralogy of the slag.

A number of finishing slags were examined. These could be divided into two types according to whether apatite was present in significant proportions or absent, the two types corresponding to casts in which fluorspar had or had not been added to the charge.

A.—*Slags Formed without the Addition of Fluorspar to the Charge.*

The phases present in these slags were: nagelschmidtite, magnesio-wüstite, lime, dicalcium silicate, and calcium ferrites. Opaque oxide phases were sometimes present in small amounts, being probably iron oxides with other oxides in solid solution. So far these have not been studied in detail nor any positive identifications made.

Nagelschmidtite ($7\text{CaO} \cdot \text{P}_2\text{O}_5 \cdot 2\text{SiO}_2$).—This usually occurs in colourless or very pale brown crystals which form the predominant constituent of the slag (Figs. 7, 8, 25, 26, and 27). Their habit varies in a general way with the proportion of magnesio-wüstite in the slag:

(a) With little magnesio-wüstite: Hypidiomorphic tabular crystals; this habit is developed only in slowly cooled slag-balls.

(b) With a moderate amount magnesio-wüstite: In small rounded grains in groups showing a parallel orientation, with magnesio-wüstite between them.

(c) With large amounts of magnesio-wüstite: As rounded isolated crystals set in magnesio-wüstite and opaque oxides. This is also common in the chilled margin of spoon samples, where nagelschmidtite occurs as rounded crystals set in a very fine-grained matrix.

The cleavage is basal (good) and prismatic (weak), the two being at right angles. On a basal section the prismatic cleavage intersects as irregular cracks. The refractive indices are: $\alpha = 1.654-1.701$, $\gamma = 1.658-1.710$, $\gamma - \alpha = 0.001-0.010$. Bxa is Z and is perpendicular to the best cleavage; $2V$ is always less than 20° and is often sensibly uniaxial.

Two types of nagelschmidtite have been noted, both of which fall within the range of optical properties described above. In the first the mineral is clear and structureless; in the second the mineral has a silky appearance between crossed nicols, the grain being approximately parallel to the best cleavage and the extinction not quite uniform. In ordinary light this gives a faintly fibrous appearance to the surface of the crystals. It is possible that here we are dealing with some form of allotropic inversion which could be checked by comparative X-ray powder photographs of the two types and of artificially prepared nagelschmidtites. Otherwise, both types show the same range of optical properties, the increase in refractive indices corresponding to an increase in proportion of silicon atoms replacing phosphorus atoms. Where the increase in refractive index is accompanied by an increase in birefringence and a change in colour, we are probably dealing with a slight additional replacement of calcium by other cations.

Two types of alteration have been recognized:

(1) Certain slags show some nagelschmidtite which is clear and colourless with a birefringence of 0.008 approximately, and in which individual crystals are very faintly turbid under low magnification and are sensibly isotropic or have a birefringence of about 0.001. Under high magnification it is seen that the mineral has a very fine grain and a fibrous component has developed whose length is generally normal to the direction of best cleavage. In sections across the fibres they can be seen as little specks of higher relief, embedded in nearly isotropic nagelschmidtite. The alteration does not necessarily go to completion in any one crystal, but can be seen partly replacing them, in a manner rather like the replacement of feldspar by myrmekite in igneous rocks.

(2) In other slags it is found that patches of the nagelschmidtite have altered to a turbid brown material of a higher birefringence (Fig. 7), or that each crystal has an outer zone, partial or complete, with these properties. It is not possible to make out much structure, except an occasional fibrous appearance. The contact of this material with nagelschmidtite when viewed under crossed nicols is usually sharp, though in ordinary light it is difficult to detect the boundary. The modification is probably due to a reaction with residual liquids in the slag. In some slags, especially where the nagelschmidtite is rather darker and buff coloured, the border is so dark as to be nearly opaque.

The constitution of this material needs confirmation but it is probably dicalcium silicate in which extensive substitution of phosphorus for silicon has taken place.

Dicalcium Silicate ($2CaO.SiO_2$).—This mineral is of common occurrence in slags of low P_2O_5 content, where it is usually present to the exclusion of nagelschmidtite, though there are indications that it may have arisen by inversion from the latter. The chief features distinguishing it from nagelschmidtite are a higher birefringence, very pale brown colour, and positive elongation along the best cleavage.

Crystals are equidimensional or tabular with straight extinction and negative elongation. A good cleavage is normal to and a weaker cleavage parallel to the length of the crystals. The crystals may be colourless, but more usually have a faint brown colour associated with a varying degree of turbidity. There may be some increase in depth of colour and development of turbidity towards the margin to the crystals, this usually being accompanied by an increase in the birefringence; but an outermost zone may have

developed of colourless clear material in the form of lozenges with a fast vibration direction parallel to their length.

The refractive indices show a wide variation: $\alpha = 1.700-1.713$, $\gamma = 1.712-1.726$, $\gamma - \alpha = 0.012-0.013$, uniaxial + or biaxial +, $2V$ less than 20° , with $Z = Bxa$ parallel to best cleavage, Opt.Ax.Pl. usually parallel to elongation.

Twinning is generally absent, but the crystals often have a silky appearance close to the positions of extinction, the fibres always showing negative elongation. In one case twinning in the two sets of lamellæ intersecting at about 60° has been observed, similar to that described by Sundius¹² for α -dicalcium silicate in portland cement clinker and shown well in the basic open-hearth slag containing tricalcium and dicalcium silicate described by Andersen and Lee.¹³

As well as occurring in the slag in independent crystals described above, dicalcium silicate can also be seen replacing crystals of nagelschmidtite in their marginal portions. It occurs as slightly turbid pale brown ingrowths of a higher birefringence; in some cases these form a complete shell (Fig. 9), but more often they are localized and show a tendency to be associated with late-crystallizing magnesio-wüstite. The boundary between the two minerals is sharp and suggests a reaction relation rather than a direct inversion, though in some cases the latter cannot be excluded.

The optical properties of dicalcium silicate are not entirely in agreement with those of either α - or β -dicalcium silicate as described by previous authors. The low value of the refractive indices is explicable on the ground that it is due to the substitution of phosphorus for silicon. The small optic axial angle is characteristic of α -dicalcium silicate (Sundius¹²), but the absence of twinning except in one case is not characteristic. Again the optic orientation is in better agreement with β - than α -dicalcium silicate, as are the spacings measured from X-ray powder photographs. Further reference to this phase will be found under apatite-bearing slags, where other features are developed.

Magnesio-wüstite ((Mg,Fe,Mn)O).—This usually occurs in drop-like crystals having no developed faces (Fig. 7) and showing a good cubic cleavage. The colour varies from pale yellow to deep red-brown or black in different slags. Magnesio-wüstite is always isotropic with refractive index greater than 1.736, the index increasing with increase in depth of colour, i.e., with increase in iron content. It has usually begun and ended crystallization later than nagelschmidtite, and it occurs in a eutectic intergrowth as rosettes set in dicalcium silicate or, more rarely, in nagelschmidtite (Fig. 26).

As well as occurring in isolated crystals, the magnesio-wüstite may occur in clots of rounded crystals associated with small amounts of nagelschmidtite and of dicalcium silicate, and here represents modified xenoliths (fragments) of the magnesite lining of the furnace. Possibly burnt dolomite may have been the source of this material, the lime having reacted with the slag constituents to give nagelschmidtite or dicalcium silicate. If this is so, in certain cases the reaction does not take place, as we find rounded magnesio-wüstite crystals set poikilitically in a base of coarse crystals of lime (Fig. 28). In some cases the cubic cleavage is seen to run in a common direction in the two phases, the magnesio-wüstite being formed by reaction of FeO from the slag with the MgO component of burnt dolomite.

In some slags a definite change from red-brown to brownish-black can be made out in the colour of the early- and late-separated magnesio-wüstite, the latter occurring interstitially and in daetylitic intergrowth with nagelschmidtite or dicalcium silicate. An analysis of a typical magnesio-wüstite from a slag-ball is given under No. 2 in Table IX. It will be seen

that it contains some lime and probably holds the bulk of the Fe_2O_3 and Al_2O_3 of the slag in solid solution.

Lime (CaO).—This is present in many of the finishing slags examined, where it occurs as isolated crystals which have separated early from the slag, it may be colourless to very pale yellow, with good cubic cleavage (Figs. 17, 18, and 19). It is isotropic and its refractive index is 1.84 approximately. In many slags it appears rather opaque and rust-coloured under low magnification; under higher magnification this is seen to be due to minute drops or vermiform masses of brown magnesio-wüstite set in colourless lime. It is evident here that we are dealing with an unmixing relation, there being a slight solubility of $(\text{Mn}, \text{Fe}, \text{Mg})\text{O}$ in lime at high temperatures. Presumably the yellow colour of some of the lime is due to a small amount of this material being held in metastable solid solution. The occurrence of lime as aggregates of coarse, well-cleaved crystals represents lime xenoliths torn away from the furnace lining or undissolved material from the charge which exists in the bath. In finishing slags these normally have a colourless lime core, associated with a little nagelschmidtite or dicalcium silicate passing marginally into a yellow-coloured lime and occasionally into an outermost, rust-coloured zone of lime with unmixed magnesio-wüstite.

Calcium Ferrites ($3\text{CaO} \cdot \text{Fe}_2\text{O}_3$, $2\text{CaO} \cdot \text{Fe}_2\text{O}_3$, $\text{CaO} \cdot \text{Fe}_2\text{O}_3$).—Both tri- and dicalcium ferrite from slags have been described.^{14, 15, 16} In both cases if the material was pure when analysed, there was extensive solid solution. Sufficient optic data were not given by Ferguson¹⁵ for tricalcium ferrite to be identified with certainty. These phases, which have been identified only as a group, occur only in very small amounts in the basic open-hearth finishing slags examined (Fig. 7); they are associated with lime, particularly in the marginal portions of some xenoliths.

B.—Slags Formed with the Addition of Fluorspar to the Charge.

The phases present in these slags were fluorapatite, nagelschmidtite, tri- and dicalcium silicate, lime, magnesio-wüstite, calcium ferrites, and unidentified oxides.

In slags containing only a small amount of apatite, the differences in the other phases are slight and the mineralogy is similar, except for apatite, to that of the slags previously described.

Lime (CaO).—Its character and early separation are identical with its occurrence in apatite-free slags.

Magnesio-wüstite ($(\text{Mg}, \text{Fe}, \text{Mn})\text{O}$).—This shows similar relations to apatite-free slags, except that the proportion of black, sensibly opaque, magnesio-wüstite of late crystallization is much higher.

Calcium Ferrites.—Where present these occur only in small amounts and the varieties have not been differentiated.

Fluorapatite ($\text{Ca}_4(\text{PO}_4)_3\text{CaF}$).—This occurs as acicular, colourless, hexagonal crystals with irregular terminations and a good basal cleavage (Fig. 12). It shows straight extinction and negative elongation. The refractive indices are: $\omega = 1.641\text{--}1.638$, $\epsilon = 1.638\text{--}1.636$, $\omega - \epsilon = 0.003$. The values are consistently slightly higher than those of pure fluorapatite ($\omega = 1.6328$, $\epsilon = 1.6290$). Twinning, with narrow lamellæ parallel and across the length of the crystals, is fairly common, giving the crystals a cross-hatched appearance when viewed between crossed nicols (Fig. 11); this phenomenon has also been noted by Schneiderhöhn.¹⁷

Partial analyses were made of three samples of pure apatite separated from typical slags by crushing, sieving, and centrifuging in liquids of adjusted specific gravity. These analyses are presented in Table III. The results show a very small substitution of sulphur and a marked substitution of silicon for phosphorus. This substitution is probably re-

TABLE III.—*Partial Analyses of Apatite from 3 Samples of Basic Open-Hearth Slag.*

	Sample 1.	Sample 2.	Sample 3.
SiO ₂ , %	2.5	2.5	2.0
CaO, %	54.2	54.1	53.8
P ₂ O ₅ , %	36.6	38.0	33.7
SO ₄ , %	0.137	0.137	0.137
ω	1.639	1.639	1.641
ϵ	1.636	1.636	1.638
$\omega - \epsilon$	0.003	0.003	0.003
	Slight twinning.	Marked twinning.	Twinning absent.

sponsible for the general increase in refractive indices as compared with those of pure fluorapatite, and has been observed to occur even more extensively in minerals of the apatite group (McConnell¹⁸).

The range of crystallization was probably long, as one can find most of the other phases except nagelschmidtite moulded upon idiomorphic apatite which may also extend into, and line cavities in, the slag. It is usually relatively free from inclusions, except those of magnesio-wüstite (Figs. 10 and 11).

Nagelschmidtite (7CaO.P₂O₅.2SiO₂).—When present this shows similar properties to that in apatite-free slags, though it is always in smaller amount, and pale brown types predominate. Its chief characteristics in these slags are a higher refractive index, *e.g.*, $\alpha = 1.688$ – 1.692 , and a stronger development of a turbid brown marginal zone of higher birefringence; in many cases this zone may completely replace the crystal. It may include magnesio-wüstite and occasionally apatite, and its relations suggest that it had crystallized before separation of dicalcium silicate and apatite had occurred. A marginal rim of dicalcium silicate commonly forms an outer portion to the crystals (Fig. 10).

Dicalcium Silicate (2CaO.SiO₂).—This varies sympathetically in amount with apatite and both vary inversely in amount with nagelschmidtite. It has a variety of habits. In slags containing nagelschmidtite (Fig. 10), it probably makes up the turbid shells of high birefringence; these may pass out into allotriomorphic granular material, pale yellow to pale green in colour, including finely dispersed magnesio-wüstite, which often has minute lozenge-shaped crystals projecting into cavities in the slag.

The optical properties of this material probably vary with the extent to which phosphorus replaces silicon. Typical samples had :

$$(a) \alpha = 1.685, \gamma = 1.701, Z - X = 0.016$$

$$(b) \alpha = 1.690, \gamma = 1.715, Z - X = 0.025$$

Both had negative elongation and were biaxial with $+2V$ small; the optic axial plane was nearly parallel to the length. On sections showing an emergence of *Bxa* lamellar twinning is occasionally seen (X twin plane = $8^\circ - 10^\circ$). In one slag the individual crystals showing the lamellar twinning are themselves twinned into pseudo-hexagonal groups, similar to those observed in β -dicalcium silicate by Sundius.¹²

The optic orientation tends to be parallel to that of nagelschmidtite, as where the latter approaches basal sections the surrounding dicalcium silicate has low birefringence; whereas where it is in prismatic sections both have a higher birefringence.

A regular growth of dicalcium silicate on apatite may occasionally be

observed; the former is in lozenges on apatite with their long axis normal to the prism of apatite (Fig. 10).

In slags with a large amount of dicalcium silicate but little or no nagelschmidite, the crystal form is different, being tabular with acute terminal faces (Fig. 12). The elongation is consistently negative: $\alpha = 1.703$, biaxial with $+2V$ small. The crystals show an extremely patchy extinction, suggesting that there has been some inversion or reaction after their crystallization from the slag, possibly the $\alpha \rightarrow \beta$ inversion of dicalcium silicate.

In the slags examined, dicalcium silicate crystallized after nagelschmidite and probably simultaneously with apatite, but the growth of idiomorphic crystals of the former on the latter indicates that it may have had a more extended range than apatite. This is not usual, as most cavities in slag contain needles of apatite alone.

Tricalcium Silicate ($3\text{CaO} \cdot \text{SiO}_2$).—This was observed in the crushed samples of some apatite-bearing slags, but not in any of the sections examined, so that its mutual relations cannot be described. Its crystallographic and optical properties were typical: Rhombohedral tablets pale green in colour, cleavage (001) poor, $\omega = 1.718$, $\omega - \varepsilon = 0.008$, uniaxial negative.

III.—THE MINERALOGY OF PREMELTING SLAGS (FREE FROM FLUORSPAR).

Having seen what is the general composition of basic open-hearth finishing slags over a limited range of composition, as represented by the chemical and mineralogical range produced at the works of the Lancashire Steel Corporation at Irlam, let us see what changes the slags show during the manufacture of steel. Slags taken from two casts were examined in detail; in cast B.8609 three samples of slag were taken during premelting stages, and in A.8605 nine samples were taken during the refining stages of manufacture.

For cast B.8609 the furnace was charged with the following material: Scrap iron 29.5, lime 3.75, limestone 3.75, scale 1.25 tons. When the furnace had heated up, 23 tons of molten iron were added from the mixer furnace.

Cast B.8609, Sample No. 1.

The first slag was sampled 10 min. after the molten metal had been added to the charge.

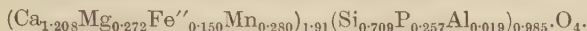
Mineralogy.—Monticellite occurs as very pale brown sheaf-like crystals growing inwards from the cooling surface of the slag, of which it makes up about 90% (Fig. 13). It has the following optical properties: $\alpha = 1.670$, $\gamma = 1.688$, $\gamma - \alpha = 0.018$, $-2V = 57^\circ$.

Apatite occurs in the heat-centre as a very few minute acicular and colourless crystals with a low birefringence, straight extinction, negative elongation, and an isotropic hexagonal cross-section.

The oxide phase is opaque and black, and occurs in skeletal crystals composed of six rays mutually perpendicular, occasionally terminated by octahedral facets, i.e., on the assumption that this phase crystallized in the cubic system, growth occurred along the tetrad axes. No positive identification of this phase has been made, but it is suggested that it is predominantly wüstite-magnetite ($\text{FeO}-\text{Fe}_3\text{O}_4$) solid solution. The skeletal crystals are enclosed in the larger crystals of monticellite; this fact, and their greater concentration at the cooling surface of the slag sample, would indicate that they crystallized largely before the monticellite. Oxide material of a brown colour also occurs as a film-like intergrowth on the outer parts of the monticellite crystals. Its exact chemical relation to the black oxide described above is not known, but it is probably a member of the same solid-solution series.

Traces of two other minerals were present, but in amounts too small to allow of identification.

Chemical Composition.—An analysis of this slag is given in Table IV. After deducting the FeO equivalent of Fe_2O_3 and recalculating the analysis on the basis of 4 atoms of oxygen per molecule, values in close agreement with monticellite group orthosilicates are obtained:



Thus the silicate phase present is a manganiferous monticellite, and of immediate interest is the extensive replacement of silicon by phosphorus in the independent SiO_4 groups of the structure; this is a similar relation to that described for dicalcium silicate in the system $\text{CaO}-\text{P}_2\text{O}_5-\text{SiO}_2$ by Barrett and McCaughey² and Trömel.³

TABLE IV.—*Analysis of Slag Sample No. 1 of Cast B.8609, with Recalculation on the Basis of 4 Atoms of Oxygen per Molecule.*

	Wt.-%.	Molecular Proportions.	Cations after Deducting FeO = Fe_2O_3 .	Cations when Oxygen = 4.
SiO_2	22.20	0.370	0.370	0.709
P_2O_5	9.53	0.067	0.134	0.257
Al_2O_3	0.50	0.005	0.010	0.019
Fe_2O_3	7.43	0.046	...	...
FeO	8.96	0.124	0.078	0.150
MnO	10.40	0.146	0.146	0.280
CaO	35.30	0.630	0.630	1.208
MgO	5.70	0.142	0.142	0.272
Total	100.02			

Cast B.8609, Sample No. 2.

This slag sample was taken 25 min. after the molten metal had been added to the charge.

Mineralogy.—Iron monticellite or olivine makes up about 70% of the slag and has the following optical properties: $\alpha = 1.720$, $\gamma = 1.753$, $\gamma - \alpha = 0.033$, $-2V = 59^\circ$; the optic axial plane is parallel to the length of the crystals.

A phase which can only tentatively be referred to the mineral steadite ($3(3\text{CaO}\cdot\text{P}_2\text{O}_5)2\text{CaO}, 2\text{CaO}\cdot\text{SiO}_2$) (Kroll¹⁹) makes up about 20% of the slag. It is in the form of hexagonal needles of a pale brown colour (Fig. 14). Its optical properties are given below and may be compared with those of true steadite given in Table II. Hexagonal needles with basal cleavage, $Nm = 1.659$, $\omega - \varepsilon = 0.003$, + elongation, uniaxial +, ω colourless, ε pale brown. Steadite shows a close similarity to apatite, as can be seen from Table V.,

TABLE V.—*Analyses of Steadite (Kroll¹⁹) Recalculated on the Basis of 24 Atoms of Oxygen per Molecule.*

	Steadite.	Steadite.	Steadite.	Apatite.
O	24.0	24.0	24.0	24.0
Si	0.64	0.63	0.53	} 6.00
P	4.93	4.97	4.83	
R'''	0.61	0.42	0.37	} 10.00
R''	9.81	9.58	10.30	
F . . . . .	...	...	...	2.00

Kroll's analyses being worked out on a basis of 24 oxygen atoms per molecule.

The steadite-like phase shows some concentration near the cooling surface of the slag sample, where it is associated with the oxide phase and monticellite, but it must have an extended range of crystallization, for it also occurs as minute needles projecting into cavities in the heat-centre of the spoon sample.

An unknown phase occurs in amounts of less than 1%. It has the form of elongated colourless crystals, possibly hexagonal in outline. The cleavage is fair both parallel and perpendicular to the elongation. Extinction is straight with positive elongation, α 1.638, γ 1.645, approximately; optic sign indeterminate, possibly biaxial +.

A trace of apatite is present, as in sample No. 1.

An oxide phase similar in occurrence and habit to that in sample No. 1 is present, though in smaller amount; it shows a concentration at the cooling surface associated with the steadite-like phase.

Chemical Composition.—The analysis of sample No. 2 is given in Table VI. After deducting FeO equivalent to Fe_2O_3 , the analysis can be recalculated as an orthosilicate of olivine type and steadite. If the steadite is assumed to be close to $4\text{CaO} \cdot \text{P}_2\text{O}_5$, from which it differs little in ratio of P_2O_5 to CaO, the olivine has the following composition: Fe_2SiO_4 40.6%, Mn_2SiO_4 26.2%, Ca_2SiO_4 19.7%, and Mg_2SiO_4 13.5%.

TABLE VI.—*Analysis of Slag Sample No. 2 of Cast B.8609, with Recalculation to Olivine and Residuum Approaching Steadite.*

	Wt.-%.	Molecular Proportions.	Less Fe_3O_4 .	Olivine.	Residuum.
SiO_2	20.20	0.337	0.337	0.337	...
P_2O_5	11.20	0.078	0.078	...	0.078
Al_2O_3	0.34	0.003	0.003	} 0.674	0.349
Fe_2O_3	4.29	0.027	...		
FeO	20.48	0.284	0.254		
MnO	11.80	0.165	0.165		
CaO	26.80	0.479	0.479		
MgO	5.00	0.122	0.122		
Total	100.11				

Cast B.8609, Sample No. 3.

This slag sample was taken just as the charge melted, about 1 hr. after the molten metal had been added from the mixer furnace.

The slag was heterogeneous, consisting of xenoliths composed predominantly of lime set in a base of nagelschmidtite, magnesio-wüstite, and a small amount of monticellite.

Mineralogy of Xenoliths.—The lime in the xenoliths amounts to about 90%; it occurs as colourless rounded crystals with a good cubic cleavage (Fig. 17). There is slight alteration to calcium hydroxide along the cleavage by reaction with the small amount of water present in the Canada balsam cement of the slice. Between the lime crystals is a dark-coloured matrix which has evidently replaced the crystals to a certain extent, for in the core of the xenoliths the lime crystals may be adjacent to each other. In the matrix the following phases may be found: magnesio-wüstite, dicalcium ferrite, nagelschmidtite, and dicalcium silicate. The magnesio-wüstite occurs as a pale yellow, magnesia-rich type adjacent to the lime, passing into a darker brown or yellow type in the body of the matrix; in certain cases it is black and opaque and presumably rich in

wüstite, though it may be similar to the oxide described by Ferguson¹⁴ and quoted in Table XII. of the present paper. Dicalcium ferrite occurs in pleochroic brown prismatic crystals of high relief, relatively sparsely scattered throughout the matrix, the best crystals growing in small cavities associated with metallic iron and magnesio-wüstite. Nagelschmidtite occurs only in the outer portions of the xenoliths and as a uniform reaction-rim surrounding them. Dicalcium silicate occurs as a few small sporadic crystals with the xenoliths. One xenolith enclosed in nagelschmidtite, differed in being composed of small rounded crystals of magnesio-wüstite, pale yellow in the core and darker towards the margin of the xenolith, all set in nagelschmidtite. This was probably derived from the periclase or burnt-dolomite banks of the furnace.

It should be noted that no tricalcium silicate was found here, though in other cases it was found associated with nagelschmidtite in cavities in lime xenoliths sampled from melting slags.

Mineralogy of the Slag.—The liquid slag in which the xenoliths existed largely as solid fragments while in the furnace, crystallized to nagelschmidtite, monticellite, and an oxide phase.

Nagelschmidtite occurs in rounded colourless crystals, often in groups showing a parallelism of orientation, the refractive index and birefringence being much lower than those observed in any finishing slag, *viz.*, $\alpha = 1.654$, $\gamma - \alpha = 0.003$; though adjacent to the xenoliths, where it forms a reaction-rim (Figs. 15 and 16) about 1 mm. thick, the birefringence is higher, $\alpha = 1.655$, $\gamma = 1.661$, $\gamma - \alpha = 0.006$. In both cases it was biaxial +, with 2V very small or nearly uniaxial.

Near the margin of the spoon sample and away from the reaction-rim around the lime xenolith, the nagelschmidtite crystals were surrounded by a thin rim of colourless material (Fig. 16), often in parallel orientation over large areas, and having a birefringence of about 0.012. It had the following properties: $\alpha = 1.657$, biaxial -, 2V moderate, optic axial plane parallel to the length of the crystals, but usually perpendicular to small laminae and cleavage within the crystal. It is thought to agree best in properties with a monticellite showing slight atomic replacement of magnesium by iron and manganese.

The oxide phase occurs as finely granular to dense material between the nagelschmidtite with which it is intergrown marginally, and the monticellite. It varies from brown to black in colour, is isotropic, and is probably an iron-rich member of the magnesio-wüstite series.

Chemical Composition.—The composition of this slag is given under cast B.8609, Sample No. 3, in Table VII. Its composition cannot be taken as a possible slag liquid because of its xenolithic character; xenolith-free material would have to be analysed to give a closer approximation to this. Table VII. shows the general chemical variation of the slags from this and some other casts, but further recasting of the analysis brings out the significant differences. It has been shown that the slags of the melting-down stage were essentially made up of monticellite-group orthosilicates with a steadite-like phase developing after the orthosilicate, and that these were replaced by a silicophosphate (nagelschmidtite) magnesio-wüstite slag with a little monticellite; lime occurred only as xenoliths in the slag.

The orthosilicate composition of premelting slags was noted by Ferguson,⁸ Mason,⁴² Wilson,⁴³ and Colclough,²⁷ though only the first two used microscopic data.

The analyses can therefore be recast in molecular proportions and the divalent bases to satisfy SiO_2 as $2\text{RO} \cdot \text{SiO}_2$, and P_2O_5 as $3\text{RO} \cdot \text{P}_2\text{O}_5$ can be calculated (*see* Table VIII.). The slags then fall into two groups: (a) Those in which CaO is not sufficient to satisfy SiO_2 and P_2O_5 , and (b) those in which CaO can more than satisfy SiO_2 and P_2O_5 . In the first case the

slags are dominantly of the orthosilicate type, and in cast B.8609 pass from a monticellite (with $\text{Ca} \gg \text{Mg} = \text{Mn} > \text{Fe}''$) to an olivine-rich phase (with $\text{Fe}'' > \text{Mn} > \text{Ca} > \text{Mg}$). The latter is associated with a steadite-like phase which in part accounts for the drop in the proportion of calcium in the orthosilicate. The limit of phosphorus substitution in monticellite which causes the appearance of this additional phosphate phase in slag No. 2 is not known. Possibly it is due to the greater deficiency of lime and greater excess of other bases as compared with slag No. 1, which is responsible for its appearance (see Tables VII. and VIII.).

TABLE VII.—Analyses of Some Basic Open-Hearth Slags from the Irlam Works of the Lancashire Steel Corporation.

Cast No.	Sample.	Content, %.										
		SiO ₂ .	P ₂ O ₅ .	TiO ₂ .	Al ₂ O ₃ .	Fe ₂ O ₃ .	FeO.	MnO.	CaO.	MgO.	S.	Total Iron
B.8609	No. 1	22.20	9.53	...	0.50	7.43	8.96	10.40	35.30	5.70	...	12.20
	No. 2	20.20	11.20	...	0.34	4.29	20.48	11.80	26.80	5.00	...	19.20
	No. 3	17.20	9.90	...	1.00	2.43	4.22	7.40	51.30	5.70	...	5.00
D.8099	No. 1	10.20	14.90	1.00	1.50	4.40	2.60	4.30	56.0	4.3	...	5.10
	No. 2	12.00	15.10	...	1.80	5.70	3.00	5.00	52.0	3.3	...	6.34
	No. 3	10.40	12.00	...	1.60	4.90	8.40	5.90	52.8	3.2	...	10.00
C.6651	No. 1	26.60	3.84	...	1.80	1.43	2.56	9.88	43.50	9.20	...	3.00
	No. 2	23.80	4.56	...	...	...	...	...	45.90	...	...	3.40
	No. 3	19.80	5.28	...	...	...	...	...	49.80	...	...	3.60
D.6652	No. 1	21.60	9.92	...	1.76	3.14	3.84	8.92	43.00	7.20	...	5.20
	No. 2	17.80	10.20	...	...	...	...	...	49.20	...	...	5.70
	No. 3	14.20	8.96	...	...	...	...	...	49.60	...	...	10.50
C.6455	No. 1	21.60	12.12	...	1.60	2.11	6.27	12.53	36.90	5.76	0.124	6.40
	No. 2	18.90	11.76	...	1.30	4.57	4.22	11.08	42.10	5.10	0.137	6.50
	No. 3	16.20	11.08	...	1.10	4.00	5.24	8.70	47.50	5.04	0.208	6.90
D.6876	No. 1	18.00	14.60	...	...	...	...	...	43.30	...	...	5.10
	No. 2	14.60	13.84	...	...	...	...	...	49.80	...	...	5.00
	No. 3	12.40	12.24	...	...	...	...	...	51.40	...	...	7.80
D.6896	No. 1	17.80	11.36	...	...	...	...	...	43.20	...	...	5.60
	No. 2	12.80	9.24	...	...	...	...	...	50.50	...	...	9.30
	No. 3	11.00	8.96	...	...	...	...	...	52.80	...	...	9.60

It will be seen that slags Nos. 1 and 2 are alike in that nearly all the divalent cations are necessary to satisfy SiO_2 as $2\text{RO} \cdot \text{SiO}_2$ and P_2O_5 as $3\text{RO} \cdot \text{P}_2\text{O}_5$. In slag No. 3, however, the available lime is enough to satisfy all the SiO_2 and P_2O_5 under these conditions; in this slag we get a silico-phosphate (nagelschmidtite) formed along with a little monticellite of later crystallization and magnesio-wüstite. In the majority of the other melting slags examined monticellite was absent, all SiO_2 and P_2O_5 being present as nagelschmidtite and dicalcium silicate.

The virtual absence of manganese from nagelschmidtite in slags with excess lime is illustrated in the analysis of this phase given under No. 1 in Table IX., which contains only 0.42% of MnO . The mixture of nagelschmidtite and magnesio-wüstite from the same slag after the separation of some of the former contained 8.71% of MnO (No. 1(a), Table IX.). Another example (No. 2, Table IX.) again shows a high percentage of MnO (11.06%).

Examination of other slags of which the phase assemblage is definitely known (Table VIII.) emphasizes the above points and brings to light others. Thus, where the deficiency of molecular proportion of CaO to satisfy

TABLE VIII.—*Molecular Analysis of Some Basic Open-Hearth Slags from the Irlam Works of the Lancashire Steel Corporation.*

Cast No.	Sample.	SiO ₂ .	RO for 2RO.SiO ₂ .	P ₂ O ₅ .	RO for 3RO.P ₂ O ₅ .	Total RO.	Avail-able CaO.	Avail-able RO.	Defi- ciency or Ex- cess of RO.	Defi- ciency or Ex- cess of CaO.	Phases Present in Crystalline Slag, Excluding Xenoliths.
B.8609	No. 1	0.370	0.740	0.067	0.201	0.941	0.630	0.996	+0.055	-0.311	Monticellite + wüstite.
	No. 2	0.337	0.674	0.078	0.234	0.908	0.479	1.020	+0.102	-0.429	Olivine + wüstite.
	No. 3	0.287	0.574	0.069	0.207	0.781	0.918	1.207	+0.426	+0.137	Nagelschmidtite + monticellite + magnesio-wüstite.
D.8099	No. 1	0.170	0.340	0.105	0.315	0.655	1.000	1.201	+0.546	+0.345	Nagelschmidtite + dicalcium silicate + magnesio-wüstite + lime.
	No. 2	0.200	0.400	0.106	0.318	0.713	0.928	1.122	+0.404	+0.210	Nagelschmidtite + dicalcium silicate + magnesio-wüstite + lime + apatite.
	No. 3	0.173	0.346	0.084	0.252	0.593	0.942	1.208	+0.610	+0.344	Nagelschmidtite + dicalcium silicate + magnesio-wüstite + lime + apatite.
C.6651	No. 1	0.443	0.886	0.027	0.071	0.957	0.777	n.d.	...	-0.180	Monticellite + wüstite.
	No. 2	0.397	0.794	0.032	0.091	0.890	0.819	n.d.	...	-0.071	Nagelschmidtite + dicalcium silicate + magnesio-wüstite.
	No. 3	0.330	0.660	0.037	0.111	0.771	0.889	n.d.	...	+0.118	Nagelschmidtite + dicalcium silicate + magnesio-wüstite + lime.
D.6652	No. 1	0.353	0.706	0.069	0.207	0.913	0.768	n.d.	...	-0.145	Nagelschmidtite + monticellite + wüstite.
	No. 2	0.296	0.592	0.073	0.219	0.881	0.878	n.d.	...	+0.067	Nagelschmidtite + dicalcium silicate + magnesio-wüstite.
	No. 3	0.234	0.468	0.063	0.189	0.657	0.885	n.d.	...	+0.228	Not determined.
C.6455	No. 1	0.353	0.706	0.085	0.255	0.961	0.659	n.d.	...	-0.302	Monticellite + wüstite (? little nagelschmidtite).
	No. 2	0.315	0.630	0.083	0.249	0.879	0.742	n.d.	...	-0.137	Nagelschmidtite + dicalcium silicate + magnesio-wüstite.
	No. 3	0.277	0.554	0.078	0.234	0.788	0.878	n.d.	...	+0.090	Nagelschmidtite + dicalcium silicate + magnesio-wüstite + apatite.
D.6876	No. 1	0.300	0.600	0.102	0.306	0.906	0.773	n.d.	...	-0.133	Nagelschmidtite + monticellite + magnesio-wüstite.
	No. 2	0.243	0.486	0.097	0.291	0.777	0.889	n.d.	...	+0.112	Nagelschmidtite + dicalcium silicate + magnesio-wüstite.
	No. 3	0.207	0.414	0.085	0.255	0.669	0.918	n.d.	...	+0.249	Not determined.
D.6896	No. 1	0.297	0.594	0.080	0.240	0.834	0.771	n.d.	...	-0.063	Nagelschmidtite + magnesio-wüstite.
	No. 2	0.213	0.426	0.064	0.192	0.618	0.902	n.d.	...	+0.284	Not determined.
	No. 3	0.183	0.366	0.063	0.189	0.555	0.943	n.d.	...	+0.388	Not determined.

n.d. = not determined.

TABLE IX.—*The Composition of Nagelschmidtit and Magnesio-Wüstite.*

1. Nagelschmidtit from cast J.6997, No. 2.

1(a). Mixture of nagelschmidtit and magnesio-wüstite separated from cast J.6997, No. 2.

1(b). Residue of magnesio-wüstite in No. 1(a), after deduction of P_2O_5 , SiO_2 , and CaO in ratios present in nagelschmidtit from No. 1.

1(c). Oxides in magnesio-wüstite in No. 1(b).

2. Magnesio-wüstite from a basic open-hearth slag-ball.

2(a). Magnesio-wüstite No. 2 in molecular proportions.

	No. 1. Wt.-%.	No. 1(a). Wt.-%.	No. 1(b). Molecular Proportions.	No. 1(c). Wt.-%.	No. 2. Wt.-%.	No. 2(a). Molecular Proportions.
SiO_2 , %	22.00	14.60	...	...	...	...
TiO_2 , %	0.45	0.42	0.002	0.46	0.30	0.004
P_2O_5 , %	12.92	9.49	...	...	...	...
Al_2O_3 , %	1.60	0.25	0.003	0.82	0.38	0.003
Fe_2O_3 , %	1.69	6.15	0.039	20.19	12.80	0.080
FeO, %	...	7.80	0.108	25.62	33.07	0.458
MnO, %	0.42	8.71	0.122	28.61	11.06	0.154
CaO, %	59.95	44.80	...	...	4.86	0.087
MgO, %	0.97	7.40	0.185	24.30	37.91	0.948

SiO_2 and P_2O_5 as $2CaO.SiO_2$ and $3CaO.P_2O_5$ respectively, is greater than 0.180, these components crystallize as monticellite. Where the deficiency lies between 0.180 and 0.070, SiO_2 and P_2O_5 occur in monticellite and nagelschmidtit; in slags with deficiencies approaching 0.180, monticellite crystallizes before nagelschmidtit; while in those with deficiency approaching 0.070, nagelschmidtit crystallizes before monticellite. Where the deficiency of lime is less than 0.070, or there is an excess of lime, nagelschmidtit forms the bulk of the slag, with a little dicalcium silicate of later crystallization. This would indicate that in some of the slags there is slight replacement of calcium by magnesium, iron, or manganese in one or both these phases.

Some slags, showing a small excess of lime over that required to form nagelschmidtit and dicalcium silicate, show no free lime in thin section. The probable explanation is that here the small excess of lime is in solid solution in magnesio-wüstite. This is confirmed by the analysis of a magnesio-wüstite from a nagelschmidtit-bearing slag given under No. 2, Table IX.

In examining slags from this point of view, it is important to exclude the types carrying xenoliths of free lime; otherwise anomalous results will be obtained, as the analysis does not represent a possible liquid corresponding to the field of the phase assemblages, *e.g.*, cast B.8609, sample No. 3, has an excess of CaO of 0.137, yet the phases which have crystallized from the liquid slag are nagelschmidtit, monticellite, and magnesio-wüstite. The excess of CaO is due to the large number of lime-rich xenoliths in the slag.

From the point of view of the phases present in crystalline slag, calculation of P_2O_5 as tetracalcium phosphate, as done by Colclough²⁰ and Wilson,⁴³ has little significance, for tetracalcium phosphate only occurs in some basic Bessemer slags (Schneiderhöhn,^{17, 22} Kroll,¹⁹ Hilgenstock,²¹ Stead and Risdale¹⁶); whereas silicocarnotite, the dominant phase, lies in the binary system $3CaO.P_2O_5-2CaO.SiO_2$, along with nagelschmidtit with which it shows extensive solid solution (Barrett and McCaughey,² Trömel,³ Bredig⁴).

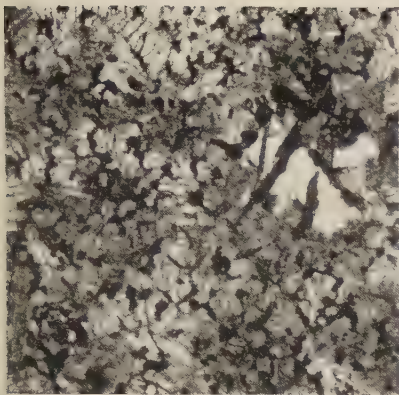


FIG. 7.—Nagelschmittite (in part inverted to β -dicalcium silicate), magnesio-wüstite, and dicalcium ferrite slag. $\times 35$.

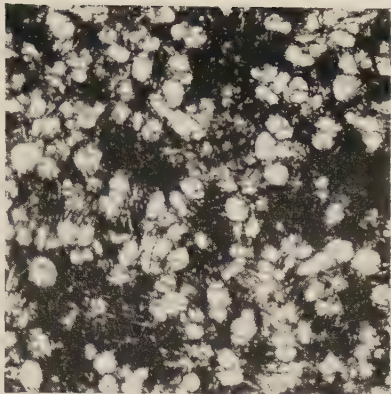


FIG. 8.—Nagelschmittite, β -dicalcium silicate, and wüstite-rich oxide slag. $\times 35$.

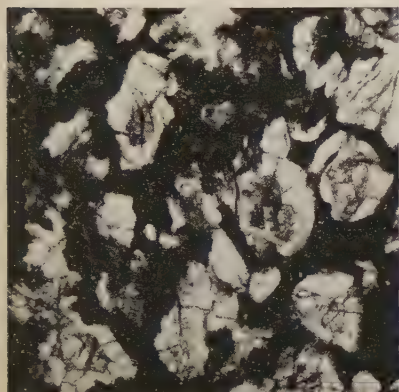


FIG. 9.—Nagelschmittite rimmed by β -dicalcium silicate in a base of magnesio-wüstite. $\times 50$, crossed nicols.

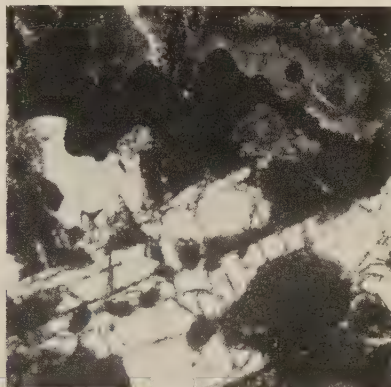


FIG. 10.—Apatite, β -dicalcium silicate, inverted nagelschmittite, and magnesio-wüstite. $\times 50$.

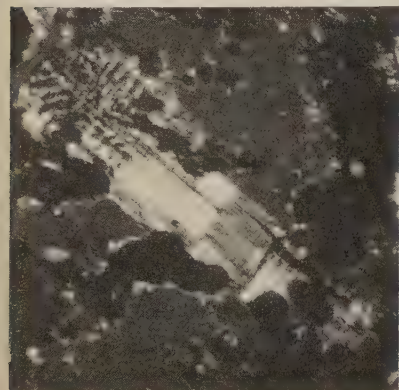


FIG. 11.—Apatite, showing twinning and inclusions of magnesio-wüstite. $\times 50$, crossed nicols.



FIG. 12.—Apatite and β -dicalcium silicate in a base of wüstite-rich oxide. $\times 35$.

Photomicrographs of Basic Open-Hearth Slags.
Unless otherwise stated, plane polarized light was used.

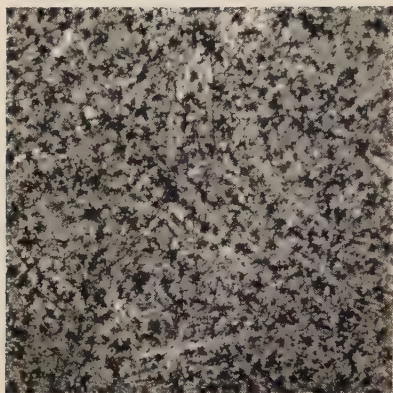


FIG. 13.—Monticellite and wüstite-rich oxide. $\times 35$.

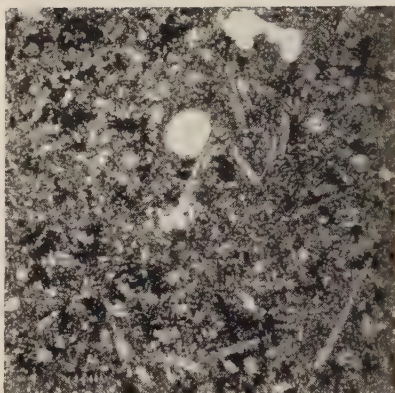


FIG. 14.—Monticellite, steadite (?), and wüstite-rich oxide. $\times 35$.

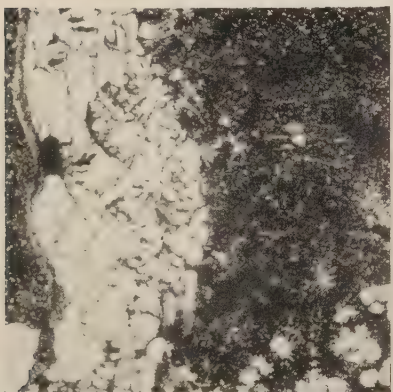


FIG. 15.—Reaction-rim of nagelschmidtite round a lime magnesio-wüstite xenolith in a slag of nagelschmidtite, monticellite, and dark magnesio-wüstite. $\times 35$.

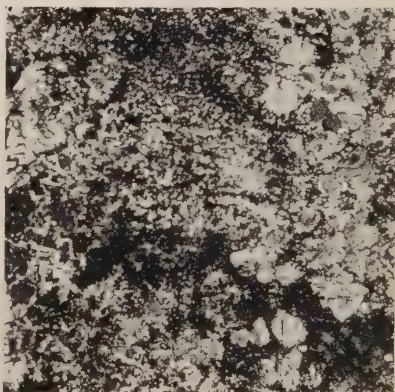


FIG. 16.—Nagelschmidtite crystals surrounded by monticellite and set in a matrix of fine-grained monticellite and magnesio-wüstite. $\times 35$, crossed nicols.

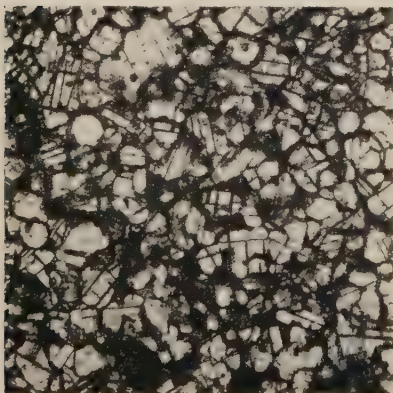


FIG. 17.—Xenolith of lime with dark oxide penetrating the cleavage planes and between the crystals. $\times 35$.

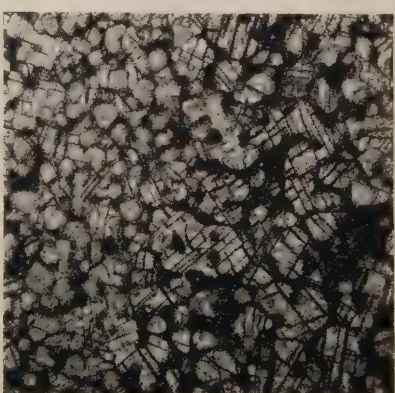


FIG. 18.—Xenolith of lime, showing two textural varieties and interstitial magnesio-wüstite. $\times 35$.

Photomicrographs of Basic Open-Hearth Slags.
Unless otherwise stated, plane polarized light was used.

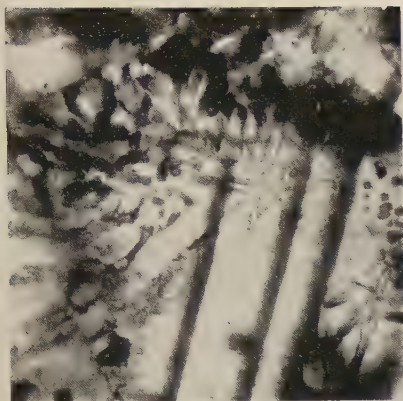


FIG. 19.—Crystal of lime in slag with a rim and verniform replacement of magnesio-wüstite. $\times 275$.



FIG. 20.—Lime xenolith showing partial replacement by magnesio-wüstite, with a reaction-rim of nagelschmidite in a monticellite-wüstite slag. $\times 35$.

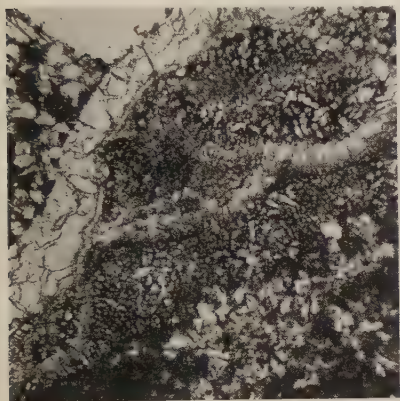


FIG. 21.—Nagelschmidite reaction-rim round a lime xenolith, showing an outer zone rich in β -dicalcium silicate and an inner zone rich in tricalcium silicate. $\times 35$.

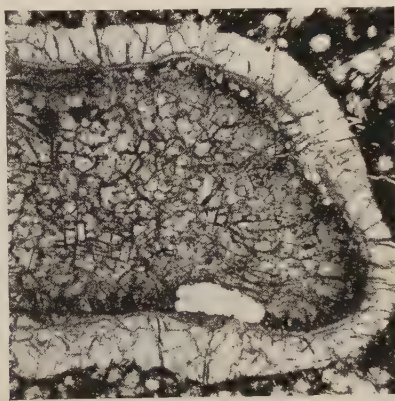


FIG. 22.—Lime xenolith in nagelschmidite β -dicalcium silicate slag, with a nagelschmidite reaction-rim and an inner narrow zone of magnesio-wüstite. $\times 35$.

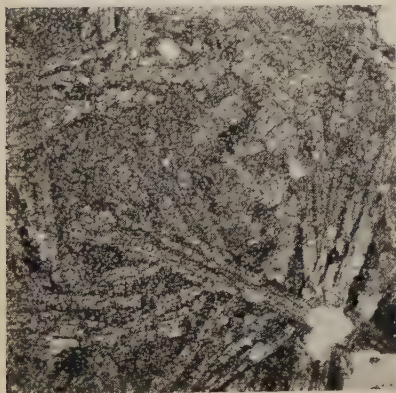


FIG. 23.—Xenolith of tricalcium silicate set in magnesio-wüstite and β -dicalcium silicate. $\times 35$.

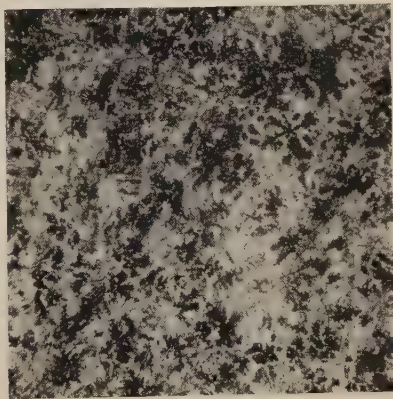


FIG. 24.—Nagelschmidite, monticellite, and wüstite-rich oxide. $\times 35$.



FIG. 25.—Nagelschmidtite, β -dicalcium silicate, and dark magnesio-wüstite. $\times 35$.

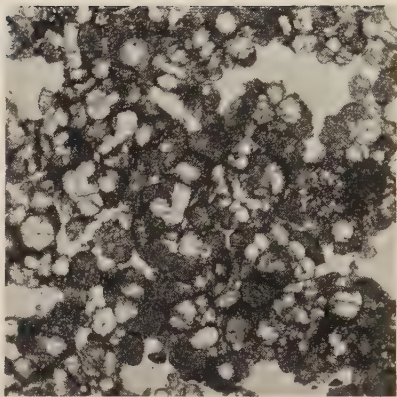


FIG. 26.—Nagelschmidtite and rosette-like intergrowth of β -dicalcium silicate and magnesio-wüstite. $\times 50$.

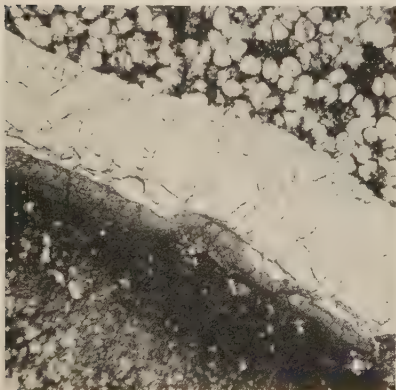


FIG. 27.—Diffusion of magnesio-wüstite into lime xenolith with a nagelschmidtite reaction-rim separating it from the slag. $\times 35$.

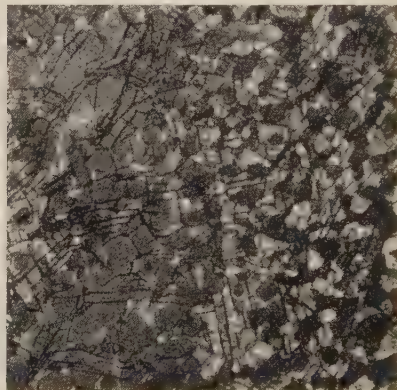


FIG. 28.—Xenolith of magnesio-wüstite and lime. $\times 50$.

Photomicrographs of Basic Open-Hearth Slags,
Unless otherwise stated, plane polarized light was used.

IV.—THE MINERALOGY OF FINISHING SLAGS (CONTAINING FLUORSPAR)

The furnace was charged with the following materials: scrap iron 33.7, lime 4.5, limestone 3.5, fluorspar 0.6 tons; when the furnace had heated up, 20 tons of molten iron were added from the mixer furnace. Between this time and the taking of the first slag sample it was estimated that a further 2.5 tons of lime were added.

The first sample was taken when the slag had melted, and samples of slag and metal were then taken at intervals till the metal had reached the desired composition. Subsequently the slag was run off into ladles, which were tipped at an isolated locality on the dumps and sampled when cold.

Cast A.8605, Sample No. 1.

The slag was just melted and contained many xenoliths of lime set in a homogeneous base. The phases present were lime, nagelschmidtite, apatite, dicalcium silicate, and magnesio-wüstite.

The xenoliths usually consist of crystalline lime that existed in the solid state while the slag was in the furnace; between the crystals of lime, nagelschmidtite and dicalcium silicate occur, the latter usually marginal to the former. When fine-grained, the lime is in pale yellow crystals; when coarse-grained, it is colourless with good cubic cleavage. Both types have dark rims due to replacement of CaO by FeO, especially on the outside of the xenolith. Magnesio-wüstite may also occur between the crystals of lime; it is brown in colour and often intergrown with nagelschmidtite.

The margin of the xenoliths is usually irregular and surrounded by a 1-mm.-wide reaction-rim of colourless nagelschmidtite. The latter is usually in clear tabular crystals with good cleavage, basal better than prismatic, $[(001) > (110)]$, with $\alpha = 1.665$, $\gamma - \alpha = 0.009$, biaxial +, with small 2V or sensibly uniaxial. The outer portions of the crystals often show a brown turbid coloration and an increase in birefringence to 0.015 (approx.) with $\alpha = 1.687$; no change is apparent in optic sign or 2V. This outer zone probably represents dicalcium silicate, with phosphorus-silicon substitution, replacing primary nagelschmidtite.

The matrix in which the xenoliths are set contains the same minerals, with apatite in addition. The apatite occurs in small colourless needles with $\omega = 1.638$, $\epsilon = 1.635$, extending into cavities in the slag and is one of the last minerals to finish crystallizing. The lime occurs in rounded isotropic crystals of high relief with a good cubic cleavage; it has a colourless, pale yellow, or brown-coloured core, surrounded by a dark brown border due to partial substitution of lime by (MnFeMg)O. The lime is always the first mineral to crystallize from the slag, and much was probably suspended as crystals in the liquid slag while in the furnace. Magnesio-wüstite occurs interstitially to the lime and is intergrown with nagelschmidtite and dicalcium silicate; the identification of the latter is uncertain, and is suggested only by the higher birefringence it shows when compared with true nagelschmidtite, and to the similarity of its relation to nagelschmidtite in more coarsely crystalline slag-balls.

Cast A.8605, Sample No. 2.

The slag is similar in phase development to the first sample, differing chiefly in the proportion of the phases and in relative freedom from xenolithic material. The chief differences are: (1) Apatite in acicular crystals is much more abundant. (2) Much less nagelschmidtite with $X = 1.668$ is present—only about 10–15%, as pale yellow crystals, marginally a turbid brown and occasionally intergrown with dactylitic magnesio-wüstite. (3) Lime is present in large amount, a pale core being surrounded

by a darker brown to brown-black border. Within the crystals thin vermiciform growths of pale magnesio-wüstite are occasionally seen (Fig. 19). (4) Magnesio-wüstite, yellow-brown in colour, also occurs intergrown with dicalcium silicate as one of the last phases to crystallize between the lime crystals and as drop-like masses marginally intergrown with them. (5) Dicalcium silicate is abundant in turbid, yellow, rounded crystals, of moderate birefringence intergrown with or surrounded by magnesio-wüstite. (6) The chilled margin of the slag shows large crystals of lime in a fine-grained base, which can be taken to indicate that they existed as such in the liquid slag.

Cast A.8605, Sample No. 3.

This slag is identical with No. 2, except that the magnesio-wüstite is red-brown in colour.

Cast A.8605, Sample No. 4.

This slag is similar in the phases present to Nos. 2 and 3, showing difference only in detail. The central parts of the sample show abundant magnesio-wüstite of a red-brown colour and of late crystallization occurring between large lime crystals with yellow margins with which it may be intergrown. In other cases the lime crystals are surrounded by an intergrowth of magnesio-wüstite in dicalcium silicate, nagelschmidite, or apatite. Between these intergrowths, and of later crystallization, occurs a dark, opaque oxide phase which occasionally grades into the red-brown magnesio-wüstite, and hence is probably a wüstite-rich solid solution. Apatite is always idiomorphic against this dark oxide, indicating that the latter ended crystallization after the former.

The quickly cooled margin of the slag sample shows larger crystals of lime set in a fine-grained base of the usual slag phases. It also shows rounded drops up to 2 mm. in dia. of a darker colour than the bulk of the slag, with a sharp margin having a very thin film of apatite between it and the slag. These drops are much richer in oxides than the bulk of the slag, being composed of deep brown, almost opaque, magnesio-wüstite in allotriomorphic crystals, with small idiomorphic needles of apatite and a few rounded, pale yellow-brown crystals of moderate birefringence which may be dicalcium silicate. These drops indicate that the liquid slag was not homogeneous, but composed of two liquids, one richer in iron, the other, greater in amount, poorer in iron. They are evidence of partial liquid immiscibility, for they are preserved only in the quenched margin of the slag sample, in the more slowly cooled core time allowed their resorption. On the other hand they may represent unresorbed droplets of slag from a different level of the furnace than that from which this spoon sample was taken, or modified particles of slag adhering to the spoon from a previous sample.

Cast A.8605, Sample No. 5.

This slag is similar in phase development to Nos. 2-4 and differs only in detail. The most interesting feature is shown in a lime xenolith (Fig. 18). At one end it is colourless to very pale yellow in rounded crystals with good cubic cleavage, and between these crystals is a dark oxide phase and small needles of apatite. The other end of the xenolith is composed of much larger, isotropic crystals with a poor cubic cleavage and coloured golden yellow. The outline of these crystals is irregular and at the centre they are full of minute dust-like inclusions. Between the crystals there is less oxide phase than in the first case. In the central portions of the xenolith there is a wide transition zone in which both the above types occur with single crystals of the first type included as drop-like, rounded crystals in

those of the yellow type; the latter can be shown to have the lower refractive index, the cleavage directions being common in both. The relations would suggest fusion of the lime, with recrystallization of the colourless type or absorption of some of the interstitial oxide phase without actual fusion, aided by the action of a volatile phase, possibly apatite, between the lime crystals. The objection to such an interpretation is that about 90% of the lime occurring in the normal slag is of the pale-coloured, well-cleaved type with a dark border, and one would have expected the transformation to the yellow type to have taken place more rapidly in the small crystals suspended at some state of its cooling in the liquid slag than in the massive xenolith.

Cast A.8605, Sample No. 6.

This slag differs little from those previously described. Apatite occurs in minute needles between the dark-coloured constituents, and there is only a trace of nagelschmidtite; where this occurs it is intergrown with magnesio-wüstite. Lime occurs in colourless, rounded or embayed crystals with good cubic cleavage and dark brown borders. It may show a marginal intergrowth with red-brown magnesio-wüstite having a dactylitic habit. The magnesio-wüstite also occurs between the lime as small rounded grains of a red-brown colour. In this slag the intergrowth between it and dicalcium silicate is well displayed, principally in brown florettes radiating from the centre of the crystals. As is usual, the magnesio-wüstite which has crystallized early is paler in colour than that which has crystallized later, which may be black and opaque.

The section of this slag shows a single small xenolith of pale yellow, rounded crystals of lime showing some increase in depth of colour from the core to the margin, where it is intergrown with red-brown magnesio-wüstite. Between the lime crystals a little nagelschmidtite or dicalcium silicate may occur.

Cast A.8605, Sample No. 7.

This slag sample was taken just before the metal was tapped, and differs in no way from No. 6.

Cast A.8605, Sample No. 8.

This specimen was taken from the cooled slag-ball after the slag had been tapped about half-way between the heat-centre and the margin. The following phases were present: nagelschmidtite, apatite, dicalcium silicate, magnesio-wüstite, and lime.

Apatite occurs in colourless, idiomorphic, acicular crystals having a hexagonal cross-section with $\omega = 1.639$. They show a distinct cross-hatched twinning (Schneiderhöhn¹⁷), with the two sets of twin lamellæ at right angles, those parallel to the length of the crystals showing the most prominent development. On basal sections no twinning is seen, only a slight patchiness of extinction. This anomalous structure does not affect the optic picture, which is consistently and truly uniaxial negative. Inclusions are of fairly frequent occurrence, being of magnesio-wüstite, nagelschmidtite, or dicalcium silicate. It is evident from the manner in which isolated crystals extend into cavities in the slag that it was one of the last minerals to end crystallization; its commencement was at some state during the separation of nagelschmidtite, for it is found both in idiomorphic and in allotriomorphic relation with it.

Nagelschmidtite is about five times as abundant as apatite in this slag; it occurs in rather irregular tabular crystals with cleavage both parallel and perpendicular to their length. In their centres the crystals are clear and nearly colourless or very pale yellow; marginally they are a turbid pale

brown, the colour change being accompanied by an increase in birefringence (0.015 approx.). Between crossed nicols the margin between the low and high birefringent types may be sharp or gradational. The clear material has $\alpha = 1.688$, $\gamma = 1.698$, $Z - X = 0.010$, biaxial +, $2V$ very small, Bra perpendicular to the tablets. Further reference to the turbid materials will be made under dicalcium silicate. The largest crystals in longitudinal sections appear homogeneous in ordinary light, but between crossed nicols they appear to be made up of several crystallographic units pseudomorphing the original crystal. This would suggest that some inversion has taken place, and that all the material which crystallized originally as nagelschmidtitite has changed into dicalcium silicate. There is some confirmation for this in X-ray powder photographs taken from a similar mineral from another slag; this shows strong dicalcium silicate lines and weak nagelschmidtitite lines.

The nagelschmidtitite is relatively free from inclusions, the commonest being red-brown magnesio-wüstite and lime. Lime occurs in rounded crystals of high relief with good cubic cleavage. When viewed under low magnification they are rusty brown in colour, but high magnification reveals that this is due to their inhomogeneity, very fine granules of red-brown magnesio-wüstite being evenly distributed through a base of colourless lime. The mutual relations of lime to the nagelschmidtitite are not easy to make out; on the whole they suggest that the bulk of the lime crystallized earlier.

Magnesio-wüstite is predominantly of a deep red-brown colour and always occurs in rounded crystals having no well-developed faces; as in the later refining-slag samples, the magnesio-wüstite of late crystallization is black in colour and nearly opaque. The general occurrence is similar to that in the spoon samples in that it had an extended range of crystallization, the bulk separating after, or in the later stages of, crystallization of the nagelschmidtitite.

Dicalcium silicate, besides the turbid variety replacing nagelschmidtitite, also occurs as clear crystals growing out from the turbid pale brown type. The crystals are lozenge-shaped with the fast vibration direction bisecting the acute angle of the apex; the positive acute bisectrix is perpendicular to the length and the optic axial angle is small; this material may be in optical continuity with that replacing nagelschmidtitite. Though no twinning has been observed, the small optic axial angle of the independent material and that replacing nagelschmidtitite would suggest that it is α -dicalcium silicate (Sundius¹²; whereas the balance of the evidence from preliminary work on X-ray powder photographs of this and similar material indicates it to be β -dicalcium silicate.

Cast A.8605, Sample No. 9.

The slag sample was taken from the heat-centre of the slag-ball and contained the same phases as No. 8, though in very different proportions.

Apatite occurs in the same amount as in No. 8 as colourless, acicular crystals with a hexagonal cross-section; its refractive indices are $\omega = 1.639$, $\varepsilon = 1.636$; the twinning is more strongly developed than in No. 8 (Fig. 11). The slag is highly vesicular, the vesicles (gas pores) being lined with apatite. It is this apatite which was analysed, the result being given under No. 2, Table III.

Nagelschmidtitite occurs in far smaller amount than in No. 8 and even that is almost entirely replaced by dicalcium silicate. It occurs in pale brown crystals with a clear centre and a turbid brown margin, which occasionally is black and opaque. The optical properties of the clear material are: $\alpha = 1.692$, $\gamma = 1.702$, $Z - X = 0.010$, biaxial +, with $2V$ very small ($< 5^\circ$). Marginally the birefringence may show a considerable

increase, up to about 0.020. The habit of the crystals is tabular with two fair cleavages, that perpendicular to the length being the better developed. Inclusions of red-brown magnesio-wüstite and lime are fairly common. In other characters this slag is similar to No. 8, except that primary dicalcium silicate and magnesio-wüstite occur in a greater amount.

Summary of Slag Relations in Cast A.8605.

The phases present in significant amounts are lime, magnesio-wüstite, nagelschmidite, apatite, and dicalcium silicate.

Lime occurs in colourless to very pale yellow, rounded crystals with a yellow-brown margin which becomes increasingly darker during the refining process. Study of the chilled margin of spoon samples shows that while in the furnace these slags were all saturated with lime and carried it as crystals in suspension in the liquid slag. There was evidence of slight solid solution of magnesio-wüstite in lime at high temperatures.

Magnesio-wüstite increases in amount throughout refining, becoming progressively enriched in iron. In any one slag the earlier-crystallized magnesio-wüstite is always paler in colour (richer in MgO) than the later-crystallized material. The prevalent occurrence of magnesio-wüstite between the crystals of lime indicates that on the whole it crystallized after the lime and at lower temperatures. Where it occurs as minute particles in the lime it is developed by exsolution; where the lime is penetrated by minute vermiform magnesio-wüstite, the latter may have been developed by unmixing or direct replacement (Fig. 19), and where it occurs marginally intergrown with the lime, replacement or simultaneous crystallization has occurred.

Apatite in the spoon samples shows a definite increase from slag No. 1 to No. 2, but then remains constant in amount. The refractive index corresponds to that in the slag-balls, though no twinning was observed; no changes in composition were detected in the apatite, which is a fluorapatite with a significant substitution of phosphorus by silicon.

Nagelschmidite is relatively abundant in slags Nos. 1 and 2, but in all other refining slags it occurs only in small amount; it is usually associated with dicalcium silicate, which forms a marginal rim to it. In the marginal portions of the finishing slag-ball, nagelschmidite is concentrated in large amount, an indication that it separates at a higher temperature than apatite. The increase in refractive indices and birefringence in the finishing slag-balls is due either to increase in the ratio of SiO_2 to P_2O_5 or to some substitution of $(\text{MnFeMg})\text{O}$ for CaO in the nagelschmidite in these slags, and, in certain cases, to its inversion to dicalcium silicate.

Dicalcium silicate has been identified independently of nagelschmidite only in slags Nos. 8 and 9, where the optical data indicate extensive replacement in it of SiO_4 by PO_4 groups. It is considered probable that the highly birefringent rim to nagelschmidite and the bulk of the birefringent material with which magnesio-wüstite is associated in slags Nos. 3-7, is composed of this phase.

In none of these slags has metallic iron been observed, except as small globules 1.0-3 mm. in dia., though it must be remembered that only transmitted light was used and the maximum magnification was about $\times 400$.

V.—THE CHEMICAL RELATIONS IN CAST A.8605.

The analyses of slag and metal samples from this cast are given in Table X.; they were carried out in the research laboratories of the Lancashire Steel Corporation at Irlam.

The weight percentage of oxides in the slag is in conformity with the

change observed in the slag phases. The general rise in CaO corresponds to the slight increase in the amount of lime in the slags. The much greater rise in FeO (or FeO + Fe₂O₃) associated with the almost constant value of the sum of MnO and MgO, corresponds to the increase in amount of magnesio-wüstite and the general increase in depth of colour of this phase. The concomitant fall of P₂O₅ and SiO₂ corresponds to a decrease in the amount of nagelschmidtite, apatite, and dicalcium silicate.

TABLE X.—Analyses of Slag and Metal Samples from Cast A.8605.

2.5 tons of lime were added between 9.30 a.m. and 10.20 a.m. An unspecified amount of scale was added between samples 1, 2, 3, 4, and 5. Spiegel was added after slag No. 7 had been sampled, and spiegel and anthracite were added to the refined metal while it was in the ladle.

Slag.		No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	
Time :	9.30 A.M.	10.28 A.M.	10.48 A.M.	11.18 A.M.	11.35 A.M.	12.2 P.M.	12.23 P.M.	12.40 P.M.	
SiO ₂ , %	...	11.0	10.2	8.9	8.8	8.4	8.4	8.4	...
P ₂ O ₅ , %	...	13.0	12.4	10.2	9.96	9.55	9.48	9.4	...
TiO ₂ , %	...	0.42	0.43	0.44	0.43	0.43	0.41	0.41	...
Al ₂ O ₃ , %	...	0.4	0.4	0.4	0.38	0.38	0.34	0.32	...
Fe ₂ O ₃ , %	...	4.72	4.43	5.85	6.0	5.14	5.72	5.72	...
FeO, %	...	5.12	6.78	8.96	9.0	9.47	10.49	10.27	...
MnO, %	...	5.78	6.24	5.67	5.48	5.14	4.86	4.78	...
CaO, %	...	55.1	54.9	55.4	55.8	56.2	56.1	56.2	...
MgO, %	...	3.96	4.1	3.88	3.6	3.6	3.6	3.4	...
S, %	...	0.398	0.398	0.336	0.310	0.310	0.316	0.316	...
Total iron, %	...	7.3	8.4	11.1	11.3	11.3	12.2	12.1	...
Metal.	Melting Sample.								Pit Sample.
C, %	0.66	0.50	0.465	0.41	0.37	0.285	0.24	...	0.30
Si, %	n.d.	0.003	n.d.	n.d.	n.d.	n.d.	n.d.	...	0.182
S, %	0.05	0.034	0.034	0.034	0.034	0.033	0.031	...	0.034
P, %	0.25	0.04	0.033	0.025	0.023	0.017	0.017	...	0.028
Mn, %	0.38	0.29	0.27	0.23	0.23	0.20	0.19	...	0.695

In the metal the most marked change is the continuous fall in carbon, a change that is not directly reflected in the slag, as the carbon is oxidized to carbon monoxide before escaping through the liquid slag. The phosphorus in the metal shows initially a rapid fall, followed by a gentle fall over the range for which we have corresponding slag samples. The percentage of P₂O₅ in the slag, however, steadily decreases; this might be due in part to formation of volatile phosphorus compounds, but is more probably due to an increase in total amount of the slag, *i.e.*, to dilution.

The manganese in the metal shows a steady decrease, and in the equivalent slags after an initial slight rise a similar decrease, which again can be explained as due to dilution.

The sulphur in the metal and slag remains nearly constant over the range of which we have simultaneous samples, its elimination if present in greater amount having taken place at an earlier stage of which no slag samples are available, *i.e.*, in premelting slags.

In order to produce graphs showing direct correlation between the changes of composition in the slag and metal, the actual weight of each constituent in both would have to be calculated. All the necessary data, in addition to analyses of simultaneous samples of slag and metal, namely the composition and weight of all the material charged, and the composition and weight of the slag and steel produced, should be available if such calculations are to be made without unnecessary assumptions and if they are to have any degree of accuracy. In the present case they have

been made, but they are based on certain assumptions and on incomplete data and therefore have not been presented.

VI.—THE XENOLITHS IN BASIC OPEN-HEARTH SLAGS.

The majority of spoon samples from the slag appear inhomogeneous when examined visually and under the microscope in thin section. These inhomogeneities are due to the fact that there are fragments of crystalline material (xenoliths) in the liquid slag while it is in the furnace. The source of the xenolithic material is dominantly the lime charged into the furnace and, to a much lesser extent, magnesia or burnt dolomite from the hearth or banks of the furnace.

All the xenoliths show a greater or lesser degree of corrosion, reaction, and modification by the slag. The study of these phenomena is important for the proper understanding of slag formation and the relations of the various phase assemblages found in slags. The following phases are found in the xenoliths: Lime, magnesio-wüstite, tri- and di-calcium silicate, nagelschmittite, apatite, and calcium ferrites, while a reaction-rim of nagelschmittite usually surrounds the xenoliths (Figs. 15, 16, 20, 21, 22, and 27).

The xenoliths are normally zoned and show a variety of structures, but a study of a number of them enables one to form a picture of the xenoliths as a whole and the general sequence of changes by which they are modified. The typical structure of a modified lime xenolith in a melting slag composed of nagelschmittite, dicalcium silicate and magnesio-wüstite is given below, starting from the practically unmodified core.

Zone 1A.—Most commonly the core is made up of colourless crystals of lime closely packed together (Figs. 17, 18, and 22), with a small amount of interstitial material varying in colour from yellow to brown or opaque black and composed probably of magnesio-wüstite or a product similar to the cindery oxide described by Ferguson.^{14, 15} More rarely, small amounts of dicalcium silicate occur. The margin of the lime crystals is usually of a yellow-brown colour, owing to the reaction with the interstitial oxide phase and its slight solid solution in the lime. Where the grain-size of the lime is small, the whole of each crystal may be pale yellow owing to the solution of some of the interstitial oxide.

Zone 1B.—Surrounding the above zone is one of the same phase assemblage but of different textural relationship. The border of the lime crystals becomes darker and brown in colour (Fig. 27), and at a certain stage one can see minute drop-like or verniform masses of brown magnesio-wüstite intergrown with the margin of the crystals and grading into the interstitial oxide phase, here composed of brown magnesio-wüstite with which may be associated a little dicalcium silicate or sometimes possibly nagelschmittite. The relations of magnesio-wüstite to lime are similar to those in certain slags, *e.g.*, A.8605, sample No. 2 (Fig. 19).

Zone 2.—The above zone may grade into one of brown magnesio-wüstite in rosette-like masses set in rounded crystals of a colourless or pale buff transparent phase, which is probably dicalcium silicate. Towards the outside of this zone the magnesio-wüstite may become so deep and dark a brown in colour as to be almost opaque.

Zone 3A.—Whereas the above two zones are massive, this one tends to be porous, with many empty spaces between the various phases developed. It is composed of brown magnesio-wüstite either as drop-like crystals or as rosettes set in dicalcium silicate similar to that in zone 2. These are associated with independent, inclusion-free, tabular crystals of tricalcium silicate (Fig. 21).

Zone 3B.—The magnesio-wüstite is similar to that in zone 3A, though

less in amount, and is associated with independent crystals of dicalcium silicate. These are easily distinguished from the tricalcium silicate of zone 3A by their higher birefringence and negative elongation (Fig. 21). In the cavities between these crystals occasional acicular crystals of apatite may be seen.

The width of the above three zones (1B to 3B) varies from 2 to 5 mm., the xenoliths in spoon samples themselves being from 2 to 10 mm. in dia.

Zone 4.—Surrounding the whole xenolith is a very thin film, about 0.2 mm. thick, composed apparently of homogeneous yellow magnesio-wüstite. This seems to merge into zone 3B, but to have a very sharp margin against the reaction-rim of nagelschmidtite (Figs. 15, 21, 22, and 27). These four zones represent the xenolith proper, where modification has been brought about by reaction between the lime of the xenolith and constituents which have diffused in from the slag. Zones 2, 3, and 4 are often partially disrupted and injected by modified liquid slag now crystallized as nagelschmidtite, dicalcium silicate, and magnesio-wüstite; the dicalcium silicate generally preponderates over nagelschmidtite, whereas the reverse is the case in the slag. This disruption is independent of cracks traversing the xenoliths, in which magnesio-wüstite, di- and tri-calcium silicate—the last in well-developed crystals—may be found.

Zone 5.—The xenolith is entirely surrounded by a 1-mm.-wide reaction-rim of colourless nagelschmidtite (Figs. 15, 20, 21, 22, and 27), the inner portion of which is very occasionally intergrown with pale yellow magnesio-wüstite. Usually the optical properties of the nagelschmidtite of the reaction-rim and that occurring in the main body of the slag are identical, though if any difference occurs that of the reaction-rim has the higher birefringence. The outer margin of the reaction-rim is clear and sharply defined and is not apparently intergrown with the phases of the main body of the slag.

Other types of xenolith have been noted and are briefly described below:

(a) Lath-like crystals of colourless tricalcium silicate with the space between filled with dicalcium silicate and pale brown magnesio-wüstite. Minute drop-like crystals of lime are included in both silicate phases. This xenolith has no reaction-rim surrounding it and is set in a melting slag composed of nagelschmidtite and magnesio-wüstite with a little dicalcium silicate (Fig. 23).

(b) The xenolith has a core of lime and yellow magnesio-wüstite which is surrounded by a zone enriched in yellow magnesio-wüstite, di- or tri-calcium ferrite, and dicalcium silicate. Small amounts of nagelschmidtite and tricalcium silicate also occur. Surrounding this is a thin film of yellow magnesio-wüstite bordered directly by a reaction-rim of nagelschmidtite; the outer portions of the latter tend to invert to dicalcium silicate, while the slag itself is composed of nagelschmidtite inverted to β -dicalcium silicate, primary β -dicalcium silicate, and brown magnesio-wüstite.

(c) Xenoliths composed predominantly of magnesio-wüstite with small amounts of lime, dicalcium silicate, nagelschmidtite, and calcium ferrites. Such xenoliths probably represent fragments torn from the modified hearth of the furnace. A portion of one of these is shown in Fig. 28; it is composed of colourless lime with good cubic cleavage, in which are set brown rounded crystals of magnesio-wüstite in which the cleavage is not so well developed, but which in some cases can be seen to be in parallel orientation with that in the lime. It probably represents a modified fragment of burnt dolomite, the iron oxide entering into solid solution in the magnesium oxide on account of the similarity of ionic radii of iron and magnesium which are markedly different from that of calcium (*see* Table I.).

Though it must be emphasized that one or more of the zones described

may be absent from the xenoliths, it is always in the melting slags that the greatest degree of complexity is found. In slags sampled towards the end of refining the xenoliths are fewer and simpler in structure, the commonest type being composed of coarsely crystalline, colourless lime with a darker border due to replacement by, or slight solid solution of, magnesio-wüstite. The latter also occurs interstitially in brown rounded crystals and may be associated with a little dicalcium silicate or nagelschmidtite. Commonly these xenoliths have no reaction-rim surrounding them, for in all of them the slag is saturated with lime; lime and nagelschmidtite are the only phases of which we have evidence of crystallization from the liquid slag while in the furnace, for it is only they that occur in large crystals in the quickly cooled marginal portions of spoon samples of finishing slags.

In the slags sampled early in the melting-down stage, xenoliths are scarcer and simple in structure. They are composed of finely crystalline or powdery lime, with a slight marginal recrystallization and enrichment in magnesio-wüstite. This is surrounded by a narrow reaction-rim of nagelschmidtite which is sharply defined from the monticellite and wüstite-rich oxide which have crystallized from the liquid slag (Fig. 20). The nagelschmidtite has crystallized as the result of the local enrichment of the slag in lime in an amount sufficient there to satisfy the P_2O_5 as $3CaO.P_2O_5$ and the SiO_2 as $2CaO.SiO_2$, and the crystallizing silicophosphate has a composition which reflects the SiO_2/P_2O_5 ratio. This enrichment of the liquid slag in lime is also apparent in melting slags where a similar reaction-rim is formed; only here is shown the marked differential diffusion of FeO , MgO , SiO_2 and, to a much lesser extent, P_2O_5 into the xenoliths. The ferrous oxide and magnesium oxide have proceeded further into the xenolith than the silica, the latter usually represented now as dicalcium silicate, though occasionally tricalcium silicate is found in regions of high lime content. Ferric oxide probably also enters, though it tends to be concentrated relative to ferrous oxide in the outer portions of the xenoliths. It is not clear as yet what is the mechanism by which was formed the thin film of magnesio-wüstite which lies immediately inside the nagelschmidtite reaction-rim.

VII.—THE RELATIONSHIP OF BASIC OPEN-HEARTH SLAGS TO THE SYSTEM $CaO-P_2O_5-SiO_2$.

A. *The System $CaO-P_2O_5-SiO_2$.*

The system $CaO-P_2O_5-SiO_2$ has recently been subject to investigation by Barrett and McCaughey² whose phase diagram is given in Fig. 1(a); the relations on the section $3CaO.P_2O_5-2CaO.SiO_2$ are given in Fig. 1(b). Only two ternary compounds, nagelschmidtite ($7CaO.P_2O_5.2SiO_2$) and silicocarnotite ($5CaO.P_2O_5.SiO_2$), occur in the system and both of these show extensive solid solution based on the substitution of phosphorus for silicon in SiO_4 groups in the structure. The only other phases showing solid solution are $2CaO.SiO_2$ and $3CaO.P_2O_5$, in which there is a similar substitution of silicon for phosphorus in PO_4 groups, or phosphorus for silicon in SiO_4 groups. For the relations in basic open-hearth slags, study of the section $2CaO.SiO_2-3CaO.P_2O_5$ is of fundamental importance, and Barrett and McCaughey show this system as a binary one within the ternary system, containing the two silicophosphates, each phase showing limited solid solution and separated from the adjacent phases by eutectics (Fig. 1(b)). The technique employed in the investigation was rather crude, so that phase boundaries and quintuple points may not be accurately located. No isothermal lines can be drawn, as no temperatures of commencement of crystallization are given, and only a few of the ternary eutectic temperatures were determined.

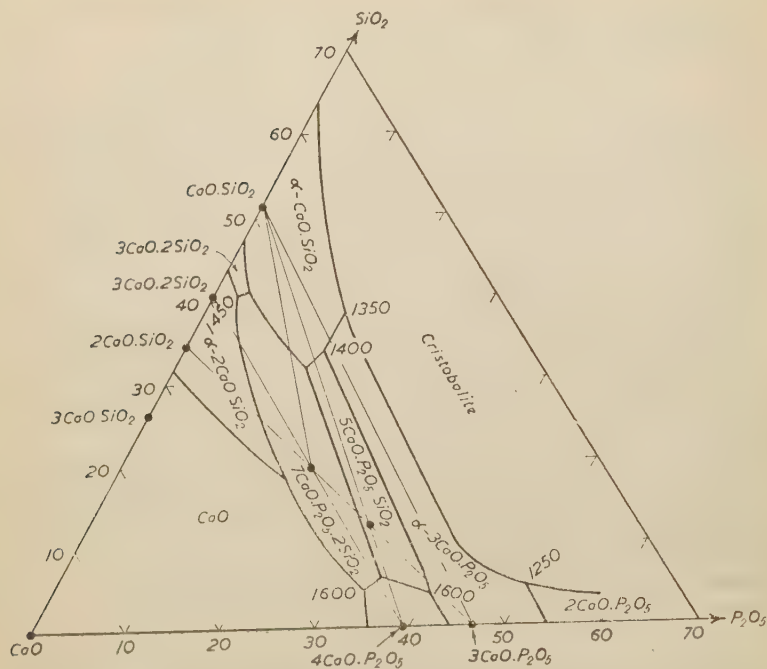


FIG. 1(a).—Part of the Equilibrium Diagram of the System $\text{CaO}-\text{P}_2\text{O}_5-\text{SiO}_2$ (after Barrett and McCaughey²).

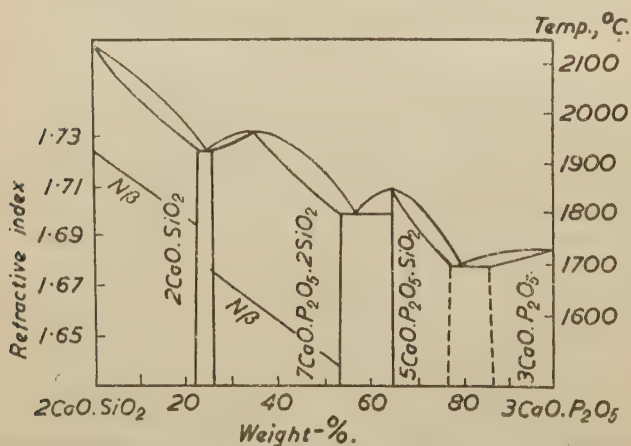


FIG. 1(b).—Equilibrium Diagram of the System $2\text{CaO}.\text{SiO}_2-3\text{CaO}.\text{P}_2\text{O}_5$ (after Barrett and McCaughey²). $N\beta$ gives the variation of refractive index (β) for dicalcium silicate and nagelschmidite.

The portion of the system $\text{CaO}-\text{P}_2\text{O}_5-\text{SiO}_2$ of most interest in relation to basic slags, namely the system $\text{CaO}-2\text{CaO}.\text{SiO}_2-3\text{CaO}.\text{P}_2\text{O}_5$, has also been described by Trömel,³ whose phase diagrams for this region and for the section $3\text{CaO}.\text{P}_2\text{O}_5-2\text{CaO}.\text{SiO}_2$ are given in Fig. 2 (a) and (b). The section

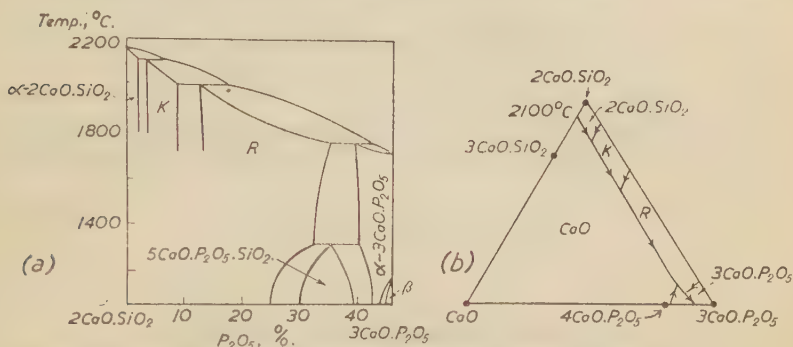


FIG. 2.—Equilibrium Diagrams of the Systems (a) $2\text{CaO}.\text{SiO}_2-3\text{CaO}.\text{P}_2\text{O}_5$ and (b) $\text{CaO}-2\text{CaO}.\text{SiO}_2-3\text{CaO}.\text{P}_2\text{O}_5$ (after Trömel³).

$3\text{CaO}.\text{P}_2\text{O}_5-2\text{CaO}.\text{SiO}_2$ shows the following features: The relation of the phases in equilibrium with liquid is one of limited solid solutions separated by reaction points, with the liquidus surface sloping from the higher-melting $2\text{CaO}.\text{SiO}_2$ at 2150°C . to the lower-melting $3\text{CaO}.\text{P}_2\text{O}_5$ at 1720°C . The maximum amount of P_2O_5 in $2\text{CaO}.\text{SiO}_2$ is 2%; at 2100°C . this phase reacts with the liquid containing 6% of P_2O_5 to give a new silicophosphate phase with 3.5% of P_2O_5 , called phase *K* by Trömel on account of its resemblance to K_2SO_4 . This phase separates from 2100° to 2000°C ., at which temperature it contains 9% of P_2O_5 and reacts with the liquid containing 18% of P_2O_5 to give a phase containing 12.5% of P_2O_5 and probably corresponding to the silicophosphate nagelschmittite, but called by Trömel phase *R*, on account of its relation to Rhenania-type phosphates. This phase separates from 2000° to 1750°C ., when it contains 36% of P_2O_5 ; at 1750°C . it reacts with the liquid containing 43% of P_2O_5 to give $\alpha-3\text{CaO}.\text{P}_2\text{O}_5$ with 39.5% of P_2O_5 and a maximum of 5% of SiO_2 as silicon replacing phosphorus. This phase is stable down to the melting point of pure $\alpha-3\text{CaO}.\text{P}_2\text{O}_5$ with 46% of P_2O_5 at 1720°C .

Over the range of compositions met with in basic open-hearth slags, the phases $\alpha-2\text{CaO}.\text{SiO}_2$, *K* and *R*, are indicated as being stable down to normal temperatures, with $2\text{CaO}.\text{SiO}_2$ and *K* and *K* and *R* co-existing over a limited range of compositions, and showing only slight exsolution. In the solid solutions of *R* richer in P_2O_5 and at compositions where *R* and $\alpha-3\text{CaO}.\text{P}_2\text{O}_5$ co-exist, it was found that a new phase corresponding to silico-carnotite appeared to 1300°C . and was not stable in contact with the liquid. The limits of composition within which this phase appeared are given as 25–43% of P_2O_5 at 1050°C ., silico-carnotite itself ranging from 30–39% P_2O_5 . (The figures given in this account are those read from Trömel's diagram and are therefore open to error, no values being given in the translation of his paper.)

Another point of interest in connection with the bounding system $\text{CaO}-3\text{CaO}.\text{P}_2\text{O}_5$, is that $4\text{CaO}.\text{P}_2\text{O}_5$ melts incongruently at about 1630°C . to CaO and liquid. This would suggest that its existence as a distinct molecule in liquid slags is unlikely, and that if any phosphate molecule is present it is $3\text{CaO}.\text{P}_2\text{O}_5$, which shows a well-defined maximum in the binary

system $\text{CaO-P}_2\text{O}_5$. It follows then that in recasting slag analyses that phosphorus should be combined as $3\text{CaO.P}_2\text{O}_5$ as indicated in Section III. of this paper.

In the ternary system $\text{CaO-2CaO.SiO}_2\text{-3CaO.P}_2\text{O}_5$ reproduced in Fig. 2, the most extensive field is that of line which separated from the fields of dicalcium silicate, K and R , by a cotectic boundary. This curve slopes from the CaO-2CaO.SiO_2 eutectic at 2150°C. to the $3\text{CaO.P}_2\text{O}_5$ eutectic at 1560°C. and from $2\text{CaO.SiO}_2\text{-3CaO.P}_2\text{O}_5$ section transition curves join it from their appropriate reaction points, all the quintuple points being ternary reaction points.

A more recent interpretation of the system $2\text{CaO.SiO}_2\text{-3CaO.P}_2\text{O}_5$ by Bredig,⁴ based largely on isotypy in A_2XO_4 structures is illustrated in Fig. 3.

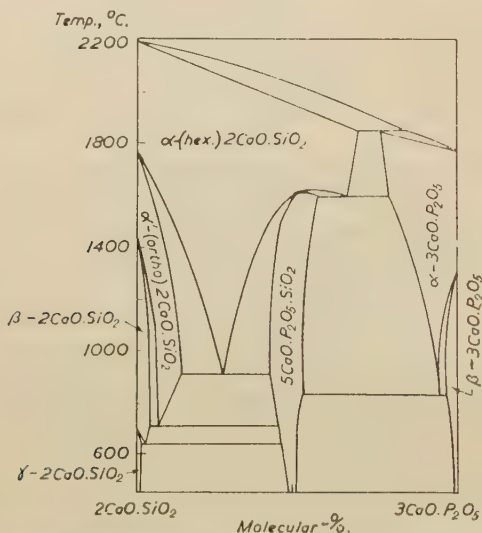


FIG. 3.— Equilibrium Diagram of the System $2\text{CaO.SiO}_2\text{-3CaO.P}_2\text{O}_5$ (after Bredig⁴).

The characteristic feature of the suggested system is the existence of a higher-temperature form of 2CaO.SiO_2 besides the normal $\alpha\text{-2CaO.SiO}_2$. This new form is suggested as hexagonal by analogy with $\alpha\text{-K}_2\text{SO}_4$, and is termed $\alpha\text{'-2CaO.SiO}_2$ by Bredig. The orthorhombic high-temperature form is called $\alpha'\text{'-(ortho)2CaO.SiO}_2$ and has a structure analogous to $\beta\text{-K}_2\text{SO}_4$. The $\alpha\text{'-(hex)2CaO.SiO}_2$ inverts to $\alpha'\text{'-(ortho)2CaO.SiO}_2$ at some temperature between 1410° and 2190°C. , the value not having been determined. $\alpha\text{'-(hex)2CaO.SiO}_2$ is shown as having continuous solid solution with $\alpha\text{'-3CaO.P}_2\text{O}_5$ and a peritectic reaction point to $\alpha\text{'-3CaO.P}_2\text{O}_5$ solid solutions at about 1880°C. in liquids with about 38% of P_2O_5 . The behaviour of $\alpha\text{'-(hex)2CaO.SiO}_2$ solid solutions on cooling depends on their composition, and can be read directly from the diagram. It will also be seen that silicocarnotite is shown as being unstable in the presence of liquid in this system, as has been demonstrated by Trömel³ and Klement and Streckenreiter.^{3a} The phases we might expect to occur in basic open-hearth slags are $\alpha\text{'-}$, $\alpha'\text{'-}$, or $\beta\text{'-2CaO.SiO}_2$, with smaller amounts of silicocarnotite, though the last might be suppressed in quenched samples. Bredig suggests that nagelschmidite is a solid solution of $3\text{CaO.P}_2\text{O}_5$ in $\alpha\text{'-(hex)2CaO.SiO}_2$, and

shows how the lines of X-ray powder photographs can be indexed in conformity with unit cell dimensions of $a = 5.38$, $c = 17.0$ Å., $c/a = 1.32$; whereas a solid solution described by Schleede³⁷ having a composition $\text{Ca}_{27}\text{P}_2\text{Si}_{12}\text{O}_{56}$ probably corresponds to a solid solution of $3\text{CaO} \cdot \text{P}_2\text{O}_5$ in α' -(ortho) $2\text{CaO} \cdot \text{SiO}_2$.*

B. The Properties of Nagelschmidtite and its Relation to Dicalcium Silicate in Basic Open-Hearth Slags.

In all the slags examined except those to which a very large amount of fluorspar had been added, the silicophosphate was very similar to nagelschmidtite in general appearance and in chemical and optical properties, the data for two analysed samples being given in Table XI.

TABLE XI.—Analyses of Nagelschmidtite Separated from Basic Open-Hearth Slags.

No. 1 from spoon sample J/2, No. 2 from slag-ball No. 24.

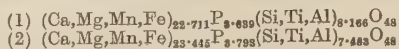
	Sample No. 1.			Sample No. 2.		
	Wt.-%.	Wt.-% less CO_2 and H_2O re-calculated to 100%.	Cations when Oxygen = 48.	Wt.-%.	Wt.-% less CO_2 and H_2O re-calculated to 100%.	Cations when Oxygen = 48.
SiO_2	20.92	22.00	7.398	19.96	20.55	6.885
P_2O_5	12.28	12.92	3.639	13.10	13.49	3.793
TiO_2	0.43	0.45	0.121	1.00	1.03	0.268
Al_2O_3	1.52	1.60	0.647	0.80	0.82	0.330
Fe_2O_3	1.61	1.69	0.455	2.03	2.09	0.536
MnO	0.41	0.42	0.121	0.67	0.69	0.206
CaO	57.64	59.95	21.650	58.70	60.44	22.250
MgO	0.92	0.97	0.485	0.87	0.89	0.453
CO_2	0.48	...	...	Nil	...	...
$\text{H}_2\text{O} + (105^\circ \text{C.})$. .	0.87	...	...	Nil	...	...
Total	97.08	...	...	97.13	...	...
<hr/>						
$2\text{CaO} \cdot \text{SiO}_2$, wt.-% .		69.4			67.0	
$3\text{CaO} \cdot \text{P}_2\text{O}_5$, wt.-% .		30.6			33.0	
γ		1.690			1.693	
α		1.680			1.682	
Optic sign and $2V$.		$+$, $< 10^\circ$			$+$, $< 10^\circ$	
Cleavage		(001) $>$ (110)			(001) $>$ (110)	

Further, variation in refractive indices was found; thus in cast A.8605 there was a progressive increase in refractive index: Sample No. 1, $\alpha = 1.665$; No. 2, $\alpha = 1.668$; No. 8, $\alpha = 1.688$; No. 9, $\alpha = 1.692$. This increase is possible because of the increase in iron and manganese replacing calcium and in silicon replacing phosphorus, particularly in No. 8 and No. 9. However, it must be borne in mind that the material in No. 8 and No. 9 may be dicalcium silicate replacing nagelschmidtite, a point yet to be confirmed by X-ray powder photographs. Nagelschmidtite with lower refractive indices is found: e.g., in B.8609, sample No. 3, $\alpha = 1.654$, $\gamma = 1.657$, $\gamma - \alpha = 0.003$, $+2V = 10^\circ$. The birefringence may also vary over a wide range from 0.001 to 0.013, probably increasing with increase in ratio SiO_2 to P_2O_5 in the solid solution. In general conformity with the above observa-

* Henceforward α - $2\text{CaO} \cdot \text{SiO}_2$ and α' - $2\text{CaO} \cdot \text{SiO}_2$ of Bredig will be referred to as α -(hex) $2\text{CaO} \cdot \text{SiO}_2$ and α -(ortho) $2\text{CaO} \cdot \text{SiO}_2$, respectively.

tions, it is found that where nagelschmidtite occurs in apatite-bearing slags it has higher refractive indices and birefringence.

Two samples of a silicophosphate of the nagelschmidtite type were separated by crushing the slag, sieving to a suitable grain-size, and centrifuging in adjusted mixtures of methylene iodide and benzene. Their analyses and optical properties are given under (1) and (2) in Table XI. If the general formula of the phases in the system $2\text{CaO} \cdot \text{SiO}_2 - 3\text{CaO} \cdot \text{P}_2\text{O}_5$ is taken as $\text{Ca}_{(281 + 3/2P)}(\text{P} \cdot \text{Si})_{12}\text{O}_{48}$, as suggested by Barrett and McCaughy,² then the analyses correspond to:



The excess of (Ca, Mg, Mn, Fe) group, 0.022 and 2.788 respectively, is probably due to included magnesio-wüstite which has not been completely eliminated in the separation. The replacement is essentially that of silicon (ionic radius 0.39 Å.) for phosphorus (ionic radius 0.35 Å.).

X-ray powder photographs have been taken of the silicophosphate analysed by Nagelschmidt³¹ and of a number from the basic open-earth slags including the two the analyses of which are given above. All agree fairly well with the spacings given by Nagelschmidt³¹ and Bredig,³⁸ with the exception of No. 1, Table XV., which shows some significant differences that have as yet not been interpreted.

If we take it as established that nagelschmidtite exists in these slags, the question then arises as to what are its relations to dicalcium silicate. Here, first of all, it should be pointed out that normally the mineral is biaxial positive with a small optic axial angle of about 5–10°, which would indicate that the symmetry is not truly hexagonal as suggested by Bredig.³⁸ However, some support is given to the idea that we may be dealing with an α -(hex) $2\text{CaO} \cdot \text{SiO}_2$ solid solution, as nagelschmidtite is often replaced by or rimmed by a dicalcium silicate of higher refractive index and birefringence (Figs. 9 and 10), this phase usually being a slightly turbid pale brown colour. The phase might be α -(ortho) $2\text{CaO} \cdot \text{SiO}_2$ solid solution of Bredig.⁴ The relations of the latter to α -(hex) $2\text{CaO} \cdot \text{SiO}_2$ (if this is nagelschmidtite) are not exactly those given by Bredig, as it universally rims and often replaces nagelschmidtite, suggesting a peritectic relationship. α -(Ortho) $2\text{CaO} \cdot \text{SiO}_2$ as it replaces nagelschmidtite (Fig. 7) extends, at least in part, over the range of composition of nagelschmidtite solid solutions, but since it crystallizes from slags rich in apatite practically to the exclusion of nagelschmidtite, it must extend in composition to higher ratios of SiO_2 to P_2O_5 . Where this turbid variety of dicalcium silicate is found, it is often rimmed by a clear zone of "granular" β - $2\text{CaO} \cdot \text{SiO}_2$ (Fig. 10), among which lozenge-shaped crystals with lamellar and mimetic twinning have been observed (Sundius¹²). Semi-quantitative analyses on rough separations (free, however, entirely from apatite) on both the dominantly clear and the dominantly turbid phases described above, showed considerable phosphorus as well as silicon, which probably accounts for the low value found for their refractive indices. Powder photographs taken of the turbid varieties of dicalcium silicate gave spacings in agreement with those of β - $2\text{CaO} \cdot \text{SiO}_2$, as quoted in Lea and Desch,²⁴ and were nearly identical with the dicalcium silicate from a $3\text{CaO} \cdot \text{SiO}_2$, $2\text{CaO} \cdot \text{SiO}_2$, (Mg, Fe)O slag described by Andersen and Lee.¹³ This latter dicalcium silicate, presumably β - $2\text{CaO} \cdot \text{SiO}_2$, shows narrow lamellae intersecting at about 50°, which therefore, according to Sundius, first crystallized as α -(ortho) $2\text{CaO} \cdot \text{SiO}_2$ and later inverted to β - $2\text{CaO} \cdot \text{SiO}_2$.

How far α -(ortho) $2\text{CaO} \cdot \text{SiO}_2$ was originally present in samples from Irlam is difficult to decide. Only in one case has the characteristic twinning been observed (very faintly developed, but in material corresponding otherwise to nagelschmidtite). In slags rich in apatite the crystals of dicalcium

silicate are sometimes replaced by a fine aggregate of crystals, and in this case we are probably dealing with α -(ortho) $2\text{CaO}.\text{SiO}_2$ inverted to β - $2\text{CaO}.\text{SiO}_2$. In the case of dicalcium silicate after nagelschmidtite, the material is more homogeneous and the latter may have inverted directly to β - $2\text{CaO}.\text{SiO}_2$. In apatitic slags the clear material growing in parallel orientation outside the turbid zone (which marks the limit of the original nagelschmidtite) is primary β - $2\text{CaO}.\text{SiO}_2$ crystallized from the liquid slag (Fig. 10). These relations are summarized in Table XII.

TABLE XII.—*The Order of Crystallization and Inversions of Nagelschmidtite and Dicalcium Silicate in Basic Open-Hearth Slags Containing Approximately Equal Amounts of P_2O_5 and SiO_2 .*

Stages in the Crystallization Process.	Slags Rich in P_2O_5 and Apatite-Free.		Slags Rich in P_2O_5 with Moderate Apatite, or Slags with Moderate P_2O_5 and No Apatite.		Slags with Low P_2O_5 and No Apatite, or Slags Rich in P_2O_5 with Abundant Apatite.	
	Phases Crystallizing.	Inversion Products.	Phases Crystallizing.	Inversion Products.	Phases Crystallizing.	Inversion Products.
1st	Nagelschmidtite		Nagelschmidtite		α -(ortho)Dicalcium silicate	
2nd	β -Dicalcium silicate	β -Dicalcium silicate	α -(ortho)Dicalcium silicate	α -(ortho)Dicalcium silicate	β -Dicalcium silicate	β -Dicalcium silicate
3rd			β -Dicalcium silicate	β -Dicalcium silicate		
	e.g., Figs. 7, 8, and 26		e.g., Figs. 9 and 10		e.g., Fig. 12	

Thus in basic open-hearth slags one may have under different conditions nagelschmidtite, α -(ortho) or β -dicalcium silicate present, but it must be borne in mind that, although preliminary X-ray evidence suggests β -dicalcium silicate replacing nagelschmidtite, the small optic axial angle of this material would be more in conformity with α -(ortho) dicalcium silicate, and this is so even where dicalcium silicate crystals have grown independently and show lamellar twinning. Again, Shepherd and Rankin's data³⁹ suggest that α -(ortho)dicalcium silicate has lamellar twinning and β -dicalcium silicate is untwinned.

The relation between nagelschmidtite and dicalcium silicate in basic open-hearth slags would seem to be a peritectic one occurring at a temperature just above that of the inversion α -(ortho) \rightleftharpoons β -dicalcium silicate, both phases showing extensive solid solution based on substitution of phosphorus and silicon.

Bearing in mind the preliminary stages of this work, we find no good agreement with the relations described for nagelschmidtite by Barrett and McCaughey, Trömel, or Bredig.

Thus, from Barrett and McCaughey's diagram (Fig. 1) we would expect a eutectic intergrowth to occur fairly commonly between dicalcium silicate and nagelschmidtite; this has not been observed. Nor does their diagram allow for the reaction relation: Nagelschmidtite + liquid \rightarrow dicalcium silicate.

From Trömel's³ diagram (Fig. 2), the general slope of the liquidus shows the peritectic reactions to be: Dicalcium silicate + liquid $\rightarrow K$ and

$K + \text{liquid} \rightarrow 7\text{CaO} \cdot \text{P}_2\text{O}_5 \cdot 2\text{SiO}_2$. The above crystallization of dicalcium silicate before nagelschmidtite and their peritectic relation are the reverse of the relations observed in the slags from Irlam. Owing to the absence of data on Trömel's phase *K* and lack of facilities for its synthesis, one cannot be sure whether or not it is present in the slags examined. However, all the material can be accounted for as α -(ortho) β -dicalcium silicate and nagelschmidtite except for that quoted under sample No. 1, Table XI., which, while optically similar to nagelschmidtite, differs in lattice spacing.

From Bredig's⁴ diagram (Fig. 3), one would not expect to find the nagelschmidtite-dicalcium silicate relation to be the peritectic one observed in these slags. The concept of nagelschmidtite being an α -(hex)-dicalcium silicate solid solution, however, is not invalidated by the present observations, its preservation in solid solutions being analogous to that of glaserite, $\text{K}_3\text{Na}(\text{SO}_4)$, in relation to α - Na_2SO_4 and α - K_2SO_4 (Bredig,^{4, 38}). That is, the $\alpha(\text{hex}) \rightleftharpoons \alpha(\text{ortho})$ inversion temperature of dicalcium silicate is greatly reduced by substitution of phosphorus for silicon. Thus α -(hex)dicalcium silicate represented by the solid solution nagelschmidtite inverts to α -(ortho)- or β -dicalcium silicate according to its composition and the temperature and composition of the slag from which it crystallizes.

C. The Phase Assemblages of Basic Open-Hearth Slags in Relation to the System $\text{CaO}-\text{P}_2\text{O}_5-\text{SiO}_2$.

In plotting the composition of basic slags for summarizing the phase associations, it was decided to take the percentage weights of CaO , P_2O_5 , and SiO_2 in the slag, to recalculate these to 100%, and to plot them on a ternary diagram of the above components (Fig 4). The justification for this lies in the phases developed in the slags, where, except in slags deficient in lime, the SiO_2 , P_2O_5 , and CaO crystallize in the phases lime, nagelschmidtite, dicalcium silicate, and silicocarnotite, independently of the MnO , MgO , FeO , Fe_2O_3 , and Al_2O_3 , which separate almost entirely as a magnesio-wüstite. So we may expect a close approximation to the relations obtaining in the system $\text{CaO}-\text{P}_2\text{O}_5-\text{SiO}_2$ in basic open-hearth slags, except in those lime-poor types in which MgO , MnO , and FeO make the deficiency in bases up to the orthosilicate ratio required for the phases which separate, namely monticellites. The extent of the variation of divalent oxides other than lime is shown in Fig. 5, where the weight percentage of $\text{MgO} + \text{MnO} + \text{FeO}$ has been plotted against the slag composition in terms of $\text{CaO} + \text{P}_2\text{O}_5 + \text{SiO}_2$ recalculated to 100%. In slags without a lime deficiency the values give a measure of the amount of magnesio-wüstite present; in the others it must be borne in mind that some of $(\text{Mg}, \text{Fe}, \text{Mn})\text{O}$ is present in orthosilicates.

It will be seen in Fig. 4 that the slags fall into fairly definite fields, which are accentuated to some extent by the paucity of analyses of slags with known phase assemblages. Commencing in the region of high SiO_2 and low P_2O_5 content and moving in the direction of increasing CaO , we have the following fields for slags from charges containing negligible or no fluorspar additions:

(1) *Monticellite + Wüstite, probably with Fe_3O_4 in solid solution.*—In these slags all the phosphorus replaces silicon in monticellite, as in cast B.8609, No. 1, the analysis of which is given in Table IV. Photographs of this and similar slags are given in Figs. 13 and 20. Mason⁴² records a spinel ($\text{RO} \cdot \text{Fe}_2\text{O}_3$) as the characteristic oxide in some monticellite slags. With the addition of lime the following reaction takes place: $2(\text{CaO} \cdot \text{RO} \cdot \text{SiO}_2) + \text{CaO} \rightarrow 3\text{CaO} \cdot \text{RO} \cdot 2\text{SiO}_2 + \text{RO}$, where $\text{R} = \text{Mg}, \text{Mn}, \text{Fe}$, passing into the second field through a narrow transition zone.

(2) *Merwinite + Wüstite-Rich Oxide.*—These slags have an oxide phase with a higher ratio of RO to R_2O_3 than that in monticellite slags, as

RO is released in the reaction $2(\text{CaO} \cdot \text{RO} \cdot \text{SiO}_2) + \text{CaO} \rightarrow 3\text{CaO} \cdot \text{RO} \cdot \text{SiO}_2 + \text{RO}$, with the result that the oxide phase, though still very dark in colour, is translucent in the thinnest of sections.

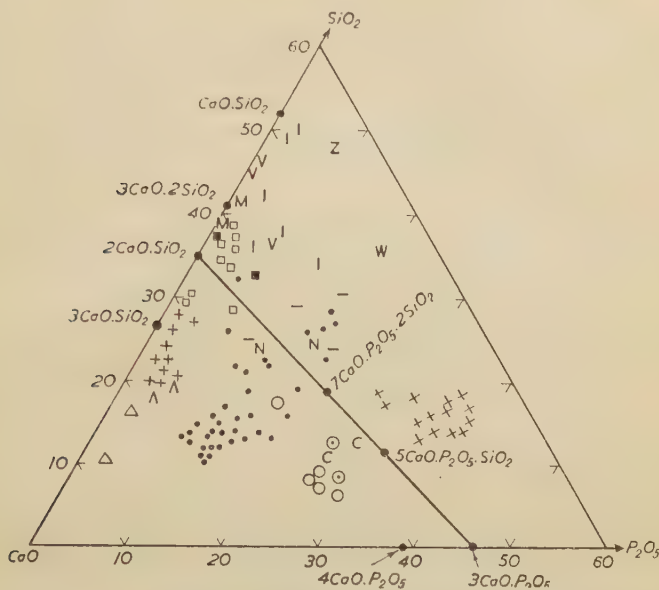


FIG. 4.—The Phase Assemblages of Basic Slags on the Ternary Diagram $\text{CaO}-\text{P}_2\text{O}_5-\text{SiO}_2$. The analytically determined contents of CaO , P_2O_5 , and SiO_2 in the slags have been recalculated to 100% and the phase assemblage given for the plotted point of this composition. The maximum amount of apatite in any slag considered was approximately 5%.

KEY.

I	$\text{CaO} \cdot \text{RO} \cdot \text{SiO}_2$	$\pm (\text{Fe}, \text{Mn})\text{O}^*$	$\pm \text{FeO} \cdot \text{Fe}_2\text{O}_3$	...	...
V	$\text{CaO} \cdot \text{RO} \cdot \text{SiO}_2 + 3\text{CaO} \cdot \text{RO} \cdot 2\text{SiO}_2$	$(\text{Fe}, \text{Mn}, \text{Mg})\text{O}$	...	...	...
M	$3\text{CaO} \cdot \text{RO} \cdot 2\text{SiO}_2$	$(\text{Fe}, \text{Mn}, \text{Mg})\text{O}$	...	...	...
■	$2\text{CaO} \cdot \text{SiO}_2 + 3\text{CaO} \cdot \text{RO} \cdot 2\text{SiO}_2$	$(\text{Mg}, \text{Fe}, \text{Mn})\text{O}$	...	...	...
□	$2\text{CaO} \cdot \text{SiO}_2$	$(\text{Mg}, \text{Fe}, \text{Mn})\text{O}$	...	± Apatite	...
+	$2\text{CaO} \cdot \text{SiO}_2 + 3\text{CaO} \cdot \text{SiO}_2$	$(\text{Mg}, \text{Fe}, \text{Mn})\text{O}$	± CaO	± Apatite	...
△	$3\text{CaO} \cdot \text{SiO}_2$	$(\text{Mg}, \text{Fe}, \text{Mn})\text{O}$	± CaO	...	$2\text{CaO} \cdot \text{Fe}_2\text{O}_3$
Λ	Cindery oxide	...	...	...	...
Z	$\text{CaO} \cdot \text{RO} \cdot \text{SiO}_2 +$ $5\text{CaO} \cdot \text{P}_2\text{O}_5 \cdot \text{SiO}_2 + \text{CaO} \cdot \text{SiO}_2$	$(\text{Fe}, \text{Mn})\text{O}$	± $\text{FeO} \cdot \text{Fe}_2\text{O}_3$	...	...
W	$2\text{RO} \cdot \text{SiO}_2 + \text{steadite}$	$(\text{Fe}, \text{Mn})\text{O}$	± $\text{FeO} \cdot \text{Fe}_2\text{O}_3$	...	...
—	$\text{CaO} \cdot \text{RO} \cdot \text{SiO}_2 +$ $7\text{CaO} \cdot \text{P}_2\text{O}_5 \cdot 2\text{SiO}_2$	$(\text{Fe}, \text{Mn}, \text{Mg})\text{O}$	...	...	...
•	$2\text{CaO} \cdot \text{SiO}_2 + 7\text{CaO} \cdot \text{P}_2\text{O}_5 \cdot 2\text{SiO}_2$	$(\text{Mg}, \text{Fe}, \text{Mn})\text{O}$	± CaO	± Apatite	...
C	$7\text{CaO} \cdot \text{P}_2\text{O}_5 \cdot 2\text{SiO}_2$	$(\text{Mg}, \text{Fe}, \text{Mn})\text{O}$	...	...	...
○	$5\text{CaO} \cdot \text{P}_2\text{O}_5 \cdot \text{SiO}_2$	$(\text{Mg}, \text{Fe}, \text{Mn})\text{O}$	...	...	...
⊙	$5\text{CaO} \cdot \text{P}_2\text{O}_5 \cdot 2\text{SiO}_2 + \text{steadite}$	$(\text{Mg}, \text{Fe}, \text{Mn})\text{O}$	± CaO	...	...
⊗	$5\text{CaO} \cdot \text{P}_2\text{O}_5 \cdot \text{SiO}_2 + 4\text{CaO} \cdot \text{P}_2\text{O}_5$	$(\text{Mg}, \text{Fe}, \text{Mn})\text{O}$	± CaO	...	...
X	$5\text{CaO} \cdot \text{P}_2\text{O}_5 \cdot \text{SiO}_2 +$ $\text{CaO} \cdot \text{RO} \cdot \text{SiO}_2 +$ " $3\text{CaO} \cdot \text{P}_2\text{O}_5$ "	± $(\text{Mg}, \text{Fe}, \text{Mn})\text{O}$	...	...	...

* The characteristic element of the oxide phase is given first.

This assemblage has been described by Mason ⁴² in P_2O_5 -free slags with 9–17% of MgO , and it is probable that if phosphorus were present in small amount it would replace silicon in merwinite. In basic open-hearth slags

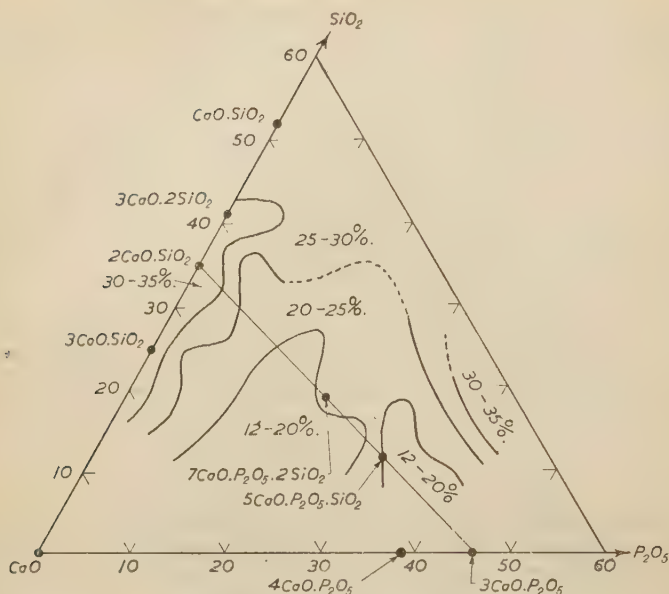


FIG. 5.—Variation of the Sum of the Percentage Weights of MgO, FeO, and MnO in Basic Slags. The figure is approximate only, as a number of anomalous values were recorded, and only 150 analyses were used in constructing the figure.

with a smaller content of MgO, merwinite may not be developed, and the field of monticellite may be adjacent to that of dicalcium silicate, transition from one to the other taking place according to the reaction: $\text{CaO} \cdot \text{RO} \cdot \text{SiO}_2 + \text{CaO} \rightarrow 2\text{CaO} \cdot \text{SiO}_2 + \text{RO}$.

Mason⁴² also records the assemblage merwinite and dicalcium silicate as being intermediate between the fields of these two phases alone. The composition of merwinite, given as $\text{Ca}_3\text{Mg}(\text{SiO}_4)_2$, apparently does not vary much in these slags, though it must be borne in mind that manganese-merwinite, $\text{Ca}_3\text{Mn}(\text{SiO}_4)_2$, has recently been described by Goldschmidt and Rait.⁴⁶

(3) *Dicalcium Silicate + Magnesio-Wüstite*.—Here the oxide again has a greater ratio of RO to R_2O_3 , since $(\text{Fe}, \text{Mg}, \text{Mn})\text{O}$ is released in the reaction $3\text{CaO} \cdot \text{RO} \cdot 2\text{SiO}_2 + \text{CaO} \rightarrow 2(2\text{CaO} \cdot \text{SiO}_2) + \text{RO}$. This change is accompanied by a change from a deeply coloured and just translucent oxide phase to a magnesio-wüstite transparent and olive to grey-brown in colour. In these slags the phosphorus again replaces silicon, but in this case in dicalcium silicate, as has been described by Barrett and McCaughey² and Trömel.⁴

With the addition of lime the following reaction takes place: $2\text{CaO} \cdot \text{SiO}_2 + \text{CaO} \rightarrow 3\text{CaO} \cdot \text{SiO}_2$, passing into the third field through a broad transition zone.

(4) *Tricalcium Silicate + Magnesio-Wüstite*.—Only a few slags of this composition have been recorded. Usually they contain a small amount of dicalcium ferrite (Mason⁴²), and they represent the liquids with the highest lime: silica ratio. Products richer in lime are known, but they are cinders and are the results of reaction without fusion and will be referred to later.

It has been shown by Andersen and Lee¹³ that, as in dicalcium silicate, phosphorus can replace silicon in tricalcium silicate. In both tricalcium-silicate- and dicalcium-silicate-bearing slags lime sometimes appears as an independent phase.

With higher concentration of phosphorus in the slag all the above four assemblages pass into silicophosphate-bearing slags carrying nagelschmidtite, the composition of which ranges from $7\text{CaO} \cdot \text{P}_2\text{O}_5 \cdot 2\text{SiO}_2$ to approximately $11\text{CaO} \cdot \text{P}_2\text{O}_5 \cdot 4\text{SiO}_2$, according to the $\text{P}_2\text{O}_5 : \text{SiO}_2$ ratio of the slag.

(5) *Nagelschmidtite + Magnesio-Wüstite + Lime*.—Only two slags have been observed in this field (see Fig. 26, though parts of this slag carry a little apatite), but between it and the above fields the following transitions have been observed :

(a) *Nagelschmidtite + Dicalcium Silicate + Magnesio-Wüstite + Lime*.—(Fig. 8).—This field extends across the $2\text{CaO} \cdot \text{SiO}_2$ – $3\text{CaO} \cdot \text{P}_2\text{O}_5$ section and, in general, slags on the silica side are lime-free and slags on the lime side carry crystalline lime (Fig. 19).

These slags in regions of high lime content have much free lime, but no tricalcium silicate has been observed, all the silica and phosphorus being combined in nagelschmidtite with smaller amounts dicalcium silicate.

(b) *Nagelschmidtite + Monticellite + Magnesio-Wüstite*.—A few slags of this type have been observed and can be considered as derived from monticellite slags in the following manner : $2(\text{CaO} \cdot \text{RO} \cdot \text{SiO}_2) + 3\text{CaO} \cdot \text{P}_2\text{O}_5 + 2\text{CaO} \rightarrow 7\text{CaO} \cdot \text{P}_2\text{O}_5 \cdot 2\text{SiO}_2 + 2\text{RO}$, where $\text{R} = \text{Fe, Mg, Mn}$. The released RO goes into magnesio-wüstite, which is correspondingly less dark in colour than the magnetite-wüstite of monticellite slags.

In both the above types we have not yet enough evidence to show the proportion of the phosphorus in the silicate and in the silicophosphate. There is no record of the assemblage nagelschmidtite + dicalcium silicate + monticellite or the assemblage nagelschmidtite + dicalcium silicate + merwinite, which might be expected to develop from dicalcium silicate + monticellite slags and dicalcium silicate + merwinite slags, respectively, with increasing phosphorus content.

(6) *Silicocarnotite + Magnesio-Wüstite + Lime*.—This assemblage is characteristic of basic Bessemer slags and varies in phase assemblage on either side of the $2\text{CaO} \cdot \text{SiO}_2$ – $3\text{CaO} \cdot \text{P}_2\text{O}_5$ section. To the lime side we have :

(a) *Silicocarnotite + Steadite + Magnesio-Wüstite*.—These tend to have higher silica and lower lime contents than $4\text{CaO} \cdot \text{P}_2\text{O}_5$ -bearing slags.

(b) *Silicocarnotite + Tetracalcium Phosphate + Magnesio-Wüstite*.—These tend to have higher lime and lower silica than the steadite-bearing slags described above. More analysed examples of slags of known phase assemblage are needed to define adequately the fields of these assemblages.

To the silica side of the $2\text{CaO} \cdot \text{SiO}_2$ – $3\text{CaO} \cdot \text{P}_2\text{O}_5$ section there occurs :

(c) *Silicocarnotite + Monticellite + Tricalcium Phosphate*.—This assemblage is described by Schneiderhöhn¹⁷ from Hoesch furnace slags.

The identification of tricalcium phosphate is not confirmed, but the position of the slags on the diagram and the optical properties of Schneiderhöhn's phase X^1 (tabular colourless crystals with positive elongation, $\gamma = 1.632$, $\gamma - \alpha = 0.0045$, optic sign not determinable) would suggest that we may be dealing with $\beta\text{-}3\text{CaO} \cdot \text{P}_2\text{O}_5$ with some

silicon replacing phosphorus. Schneiderhöhn,¹⁷ however, concluded that this was a calcium magnesium silicophosphate.

Two slags of exceptional composition have been noted, *Z* and *W* (Fig. 4):

Z = *Monticellite* + *Silicocarnotite* + *Wollastonite* + *Wüstite*.—The origin of this slag is not known, the sample having been taken from an isolated example on the slag-dumps.

W = *Olivine* + *Steadite* + *Wüstite*.—This is a melting-down slag from cast B.8609, No. 2 (Fig. 14). The high ratio of iron oxide to lime associated with the high silica and phosphorus content is probably responsible for ferrous oxide entering a silicophosphate phase.

The field of nagelschmidtite passes into that of silicocarnotite through slags carrying both these phases; no analyses of such slags are available, though one is illustrated by Barrett and McCaughey.²

In all slags a proportion of the iron is in the ferric state; this proportion varies from 1 to 6%, though it occasionally may rise as high as 15%. This iron and the aluminium (less than 2% of Al_2O_3) is normally in solid solution in wüstite or magnesio-wüstite, the former tending to occur in slags rich in silica and poor in phosphorus. In the slags so far examined calcium ferrites occur only in very small amounts, except in tricalcium silicate slags; but where they are present, Fe_2O_3 and Al_2O_3 are, in part, contained in them.

Microscopic examination of the slags shows free lime to be present in many cases. All assemblages may have xenoliths of lime in the process of absorption, but only those slags well to the lime side of the $2\text{CaO}.\text{SiO}_2-3\text{CaO}.\text{P}_2\text{O}_5$ section contain lime which has actually crystallized from the liquid slag, as when present in small amounts it enters in solid solution in magnesio-wüstite.

D. The Variation of Phase Assemblages from Melting-Down to Finishing Slags.

The first reactions in the heating up of a charge within a furnace probably take place in the solid state before fusion. Diffusion of the oxidized metal proceeds into the lime with the formation of cindery products without any well-defined composition. Two products from the top of melted-down scrap, which are probably of a similar nature, have been analysed by Ferguson¹⁴ and their composition is as follows:

	Sample No. 1.	Sample No. 2.
SiO_2 , %	2.80	7.00
P_2O_5 } %	1.00	2.40
Al_2O_3 }		
Fe_2O_3 , %	13.60	12.50
FeO , %	50.14	32.79
MnO , %	3.82	6.62
CaO , %	24.50	34.20
MgO , %	3.82	4.69

Both of these are described as being homogeneous, and it is they and free lime which react with the molten iron and the impurities it contains to form the first true slags. These primary slags are composed principally of monticellite and an oxide phase, probably a wüstite-rich solid solution, and are small in bulk. The monticellite formed may vary widely in composition within the limits $\text{XY}(\text{Si,P})\text{O}_4$, where $\text{X} = \text{Ca}$ and $\text{Y} = \text{Fe}^{++}, \text{Mn}, \text{Mg}$, and may show extensive solid solution with, or be replaced by, an olivine containing only a small amount of calcium.

The further general trend in variation of the phase assemblage of basic

open-hearth slags can be read from a study of Fig. 4 in conjunction with Fig. 6. These changes can be considered in three main types of slag, but it must be remembered that they merge indefinitely into each other.

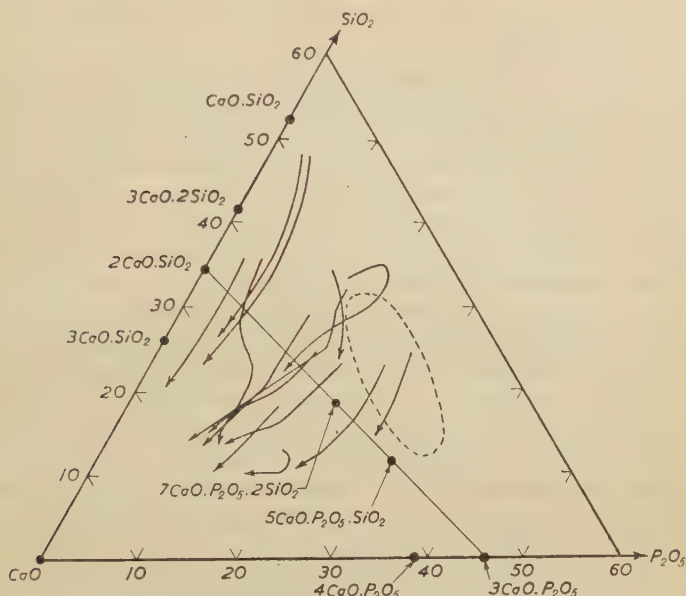


FIG. 6.—The Trend of Slag Composition from Melting to Tapping. Percentages of CaO , P_2O_5 , and SiO_2 recalculated to 100%. Data from the Irlam Works, Ferguson,¹⁴ Colclough²⁰, and Mason.⁴² The dotted line encloses the melting slags of Colclough.²⁰

(i) *Slags with Phosphorus Predominantly Contained in Silicates.*—Monticellite slags pass with absorption of lime into dicalcium silicate slags, with merwinite sometimes appearing as an intermediate phase. The components displaced from the orthosilicate appear now in magnesio-wüstite not wüstite. With further solution of lime in the slag, tricalcium silicate is produced at the expense of dicalcium silicate, without any fundamental change in the accompanying oxide phase (Mason⁴²). Very few slags are known in which tricalcium silicate occurs to the exclusion of dicalcium silicate. In both types of slag lime may be present; its association with dicalcium silicate would not be expected, but there are several possible explanations; the lime may be xenocrystal; or in slags, as in most systems containing tricalcium silicate, its field may be small, and those of dicalcium silicate and lime be adjacent, or equilibrium may not have been established in the particular sample.

(ii) *Slags with Phosphorus Predominantly Contained in Silicophosphates.*—Monticellite slags pass with absorption of lime into nagelschmidtite-bearing types, and, as before, the displaced components from monticellite cause the oxide phase which crystallizes to change from a wüstite to a magnesio-wüstite. The latter shows an increase in $\text{FeO} + \text{Fe}_2\text{O}_3$ and FeO relative to Fe_2O_3 as refining proceeds.

Nagelschmidtite slags vary with the degree of saturation of the slag with lime. Three types may be recognized:

(a) *Undersaturated*: nagelschmidtite + monticellite + magnesio-wüstite.

(b) *Saturated*: nagelschmidtite + dicalcium silicate + magnesio-wüstite.

(c) *Oversaturated*: nagelschmidtite + dicalcium silicate + lime + magnesio-wüstite.

Which of these occurs is dependent on the $\text{CaO} : \text{P}_2\text{O}_5 : \text{SiO}_2$ ratio in the slag. In all cases monticellite or dicalcium silicate shows a reaction relation to nagelschmidtite, which is usually the first phase to separate from the slag.

(iii) *Slags with Phosphorus Predominantly Contained in Fluorapatite*.—These are the slags in which fluorspar was added to the charge. No samples were available of melting-down slags of this type, and it is conjectured that they are typical monticellite-apatite-wüstite slags. The general effect of spar additions is that as much phosphorus and lime are combined with it as will satisfy the fluorine as fluorapatite. As a result, the phase assemblage of any crystalline slag, excluding its apatite, is characteristic of a fluorspar-free slag with a higher ratio of silica to phosphorus. The effect of variable addition of fluorspar to any slag assemblage can thus be read off in a qualitative way from Fig. 4. The only apatite-bearing slag on record which is deficient in lime is noted by Hallimond and Bainbridge⁴⁰ and contains monticellite. In the samples examined the most common phase assemblage was apatite + dicalcium silicate + oxides or apatite + dicalcium silicate + nagelschmidtite + oxides; the amount of apatite and nagelschmidtite varied inversely. In those types containing nagelschmidtite (now inverted to β -dicalcium silicate), in however small an amount, it was observed that it had always crystallized at a very early stage before and independently of apatite. How fluorspar additions affect the constitution of liquid slag is still conjectural, but an indication that the phosphorus may be largely stabilized as the fluorapatite molecule would seem to follow from the higher refractive indices (and hence higher ratio $\text{SiO}_2 : \text{P}_2\text{O}_5$) of nagelschmidtite in slags to which fluorspar additions have been made, as compared with apatite-free slags.

VIII.—SUGGESTIONS FOR FURTHER INVESTIGATION.

The data presented here are not enough for generalizations to be made on the constitution of crystalline slags or their bearing on the constitution of liquid slags, as only a preliminary survey has been made of a very limited number of basic slags, which do not adequately cover the possible ranges of composition. The first requirement of future work is to extend phase descriptions to a comprehensive series of slags. Even in those studied, a number of points have hardly been investigated, such as the identity and relations of opaque phases which may be present in large amounts in melting-down slags and in apatite-rich refining slags. Nor has the possible distribution of fine-grained metallic iron been studied. Again, there is still some doubt as to the identity of certain phases, which can be resolved only by further chemical, optical, and X-ray study, *e.g.*, on α - and β -dicalcium silicate, merwinite, and steadite.

IX.—ACKNOWLEDGMENTS.

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REFERENCES.

1. WHITE : *Journal of The Iron and Steel Institute*, 1943, No. II., p. 579.
2. BARRETT and MCCAUGHEY : *American Mineralogist*, 1942, vol. 27, p. 680.
3. TRÖMEL : *Stahl und Eisen*, 1943, vol. 63, p. 21.
4. BREDIG : *American Mineralogist*, 1943, vol. 28, p. 594.
5. WINCHELL : "Elements of Optical Mineralogy." New York : John Wiley.
6. WINCHELL : "Microscopic Characters of Artificial Minerals." New York : John Wiley.
7. LARSEN and BERMAN : "The Microscopic Determination of the Non-Opaque Minerals," *U.S. Geological Survey Bulletin*, No. 848.
8. DANA : "Text-Book of Mineralogy." New York : John Wiley.
9. ROGERS and KERR : "Thin-Section Mineralogy." New York : McGraw-Hill.
10. HARTSHORNE and STUART : "Crystals and the Polarizing Microscope." London : Arnold.
11. JOHANSEN : "Manual of Petrographic Methods." New York : McGraw-Hill.
12. SUNDIUS : *Zeitschrift für anorganische und allgemeine Chemie*, 1933, vol. 213, p. 343.
13. ANDERSEN and LEE : *Journal of the Washington Academy of Science*, 1933, vol. 23, p. 338.
14. FERGUSON : *Journal of the West of Scotland Iron and Steel Institute*, 1934-5, vol. 42, p. 13.
15. FERGUSON : *Journal of the Royal Technical College Metallurgical Club, Glasgow*, 1927-8, vol. 6, p. 9.
16. STEAD and RIDSDALE : *Journal of The Iron and Steel Institute*, 1887, No. I., p. 222.
17. SCHNEIDERHÖHN : *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1931, vol. 13, p. 109.
18. MCCONNELL : *American Mineralogist*, 1937, vol. 22, p. 977.
19. KROLL : *Journal of The Iron and Steel Institute*, 1911, No. II., p. 126.
20. COLCLOUGH : *Journal of The Iron and Steel Institute*, 1923, No. I., p. 267.
21. HILGENSTOCK : *Stahl und Eisen*, 1883, vol. 3, p. 498.
22. SCHNEIDERHÖHN : *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1928, vol. 10, p. 213.
23. HANSEN, BROWN MILLER, and BOGUE : *Journal of the American Chemical Society*, 1928, vol. 50, p. 396.
24. LEA and DESCH : "The Chemistry of Cement and Concrete." London : Arnold.
25. PHEMISTER : *Mineralogical Magazine*, 1942, vol. 26, p. 225.
26. PARKER and NURSE : *Journal of The Iron and Steel Institute*, 1943, No. II., p. 475.
27. BOWEN, SCHAIRER, and POSNJAK : *American Journal of Science*, 1933, vol. 26, p. 193.
28. SOSMAN and MERWIN : *Journal of the Washington Academy of Science*, 1916, vol. 6, p. 532.
29. CARNOT and DAUBREE : *Comptes rendus*, 1883, vol. 97, p. 316.
30. HILL, HENDRICKS, JEFFERSON, and REYNOLDS : *Industrial and Engineering Chemistry (Industrial Edition)*, 1937, vol. 29, p. 1299.
31. NAGELSCHMIDT : *Journal of the Chemical Society (London)*, 1937, Part I., p. 865.
32. TRÖMEL and SCHNEIDERHÖHN : *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1932, vol. 14, p. 25.
33. TERMIER and RICHARD : *Bulletin de la Société française de Minéralogie*, 1895, vol. 18, p. 391.
34. FRONDEL : *American Mineralogist*, 1941, vol. 26, p. 145.
35. TILLEY : *Mineralogical Magazine*, 1942, vol. 26, p. 190.
36. KLEMENT and STRECKENREITER : *Zeitschrift für anorganische und allgemeine Chemie*, 1940, vol. 245, p. 236.
37. SCHLEEDE : *Angewandte Chemie*, 1940, vol. 53, p. 65.
38. BREDIG : *Journal of Physical Chemistry*, 1942, vol. 46, p. 747.
39. SHEPHERD and RANKIN : *Industrial and Engineering Chemistry*, 1911, vol. 3, p. 211.
40. BAINBRIDGE : *The Iron and Steel Institute*, 1931, Carnegie Scholarship Memoirs, vol. 10, p. 1.
41. BOWEN and SCHAIRER : *American Journal of Science*, 1935, vol. 29, p. 151.
42. MASON : *Journal of The Iron and Steel Institute*, 1944, No. II., p. 69 P.
43. WILSON : *Journal of The Iron and Steel Institute*, 1920, No. I., p. 265.
44. HAY, FERGUSON, and WHITE : *The Iron and Steel Institute*, 1938, Special Report No. 22, p. 52.
45. WHITELEY : *Proceedings of the Cleveland Institution of Engineers*, 1922, No. 2, p. 36.
46. GOLDSCHMIDT and RAIT : *Nature*, 1943, vol. 162, p. 356.

For Correspondence on this Paper see the *Journal*, 1946, No. I.

MOULD AND CORE PAINTS AND WASHES, AND PARTING POWDERS.*

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Paper No. 14/1945 of the Steel Castings Research Committee (submitted by the Moulding Materials Sub-Committee).

SYNOPSIS.

The inception of the investigation on non-siliceous alternatives to silica flour for parting powders and mould and core paints is described. Alternatives to silica flour for parting powders which are quite satisfactory in foundry use are indicated. The trials made with mould and core paints indicate that silica flour can be satisfactorily replaced by non-siliceous materials. Calcined ball clay or aluminous fireclay is satisfactory for small and medium steel castings; for larger castings sillimanite, calcined or fused alumina, and zircon have given satisfactory results. The choice of the most suitable alternative depends on the particular condition of foundry practice.

It has long been recognized that workers engaged in certain steel-foundry operations are exposed to the risk of silicosis, and certain of these operations, such as fettling, are included in the Various Industries (Silicosis) Scheme, 1931, made under the Workmen's Compensation Acts. In January, 1943, H.M. Chief Inspector of Factories, following on an expression of his grave concern at the marked increase in the number of certificates granted by the Silicosis Medical Board under the above Scheme to operatives in steel foundries such as dressers, fettlers, &c., appointed a Committee to consider and to advise as to the best practicable means of preventing the production or the inhalation of dust in steel-foundry processes and the possibility of reducing the use of materials containing free silica. This Committee reached certain conclusions, which are embodied in the First Report on Dust in Steel Foundries (H.M. Stationery Office, 1944). Among the recommendations to H.M. Chief Inspector of Factories based on these conclusions are the following :

Core and Mould Paints.—The use of such paints containing free silica should be prohibited as soon as sufficient quantities of suitable alternative non-siliceous materials are available.

Parting Powders.—The use of parting powders containing free silica should be prohibited.

Following an approach through The Iron and Steel Institute to the Steel Castings Research Committee, consideration was given to these matters by its Moulding Materials Sub-Committee. This Sub-Committee, following laboratory investigations, had already initiated a comprehensive series of trials in steel foundries, in which they have had the co-operation of the Foundry Practice Sub-Committee.

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As a result of these investigations and foundry trials, the Moulding Materials Sub-Committee reported as follows:

Core and Mould Paints.—The observations made in foundries indicate clearly that paints prepared from silica flour are a possible source of silica dust arising either during the preparation of the paint, during spraying, &c., or subsequently in the dried state during easing or fettling.

Parting Powders.—It is quite practicable, efficient, and economic to use parting powders containing no free silica.

Examples of non-siliceous parting powders which have been proved to be quite satisfactory in practice are those prepared from finely ground limestone or dolomitic limestone, or precipitated calcium carbonate. These materials are usually waterproofed by thorough admixture with a small proportion of calcium or aluminium stearate, or a wax such as paraffin wax. Other satisfactory non-siliceous materials have been prepared from calcined aluminous fireclay and sillimanite.

The initial series of experiments indicated that from the technical viewpoint it would be practicable and efficient to use paints prepared from such non-siliceous materials as sillimanite, calcined or fused alumina, or china clay calcined to vitrification. A comprehensive series of trials with these and other materials has been carried through in a number of steel foundries under ordinary conditions of foundry practice.

The technique of preparing the paint needs no modification when the non-siliceous materials are used in place of silica flour, using the same suspensory agents, but small modifications in the density of the paint may be desirable to suit individual foundry practices. The particle size of the silica flour used has been found to vary over a wide range, the specific surface of this material in use in foundries for paint production varying between 1500 and 10,000 sq. cm./g. The paint prepared from the finer material spreads well and gives a thin adherent coat, but some foundries prefer the thicker coat given by the coarser material, especially on the larger sizes of cores and moulds, even though the skin may be less smooth. The same range of particle size has been found to be applicable with the alternative materials.

A fundamental difference between silica and the non-siliceous materials used in the trials is that the former expands at high temperature (*i.e.*, above 1470° C.) because of the trend for the quartz with a sp. gr. of 2.65 to invert to cristobalite or tridymite with a sp. gr. of 2.28–2.33, whilst the latter show either no permanent volume change or a small shrinkage. It has been shown, however, that silica paint mixtures undergo a small shrinkage at high temperature, owing to drying and sintering, when test-pieces prepared from the paint mixture with 7% of water are dried and fired at 1600° C. T. R. Walker, in a series of tests, found that fused alumina and zircon paint mixtures show about the same shrinkage as silica in this test, but calcined china clay shrinks much more. Further laboratory work and foundry trials are necessary before the effect of this characteristic, which will be affected by the particle size of the material, can be evaluated. It may be of more importance with large than with small castings, as one non-siliceous material which shows a much higher shrinkage than silica in the above test is giving completely satisfactory results with small and medium-size castings.

The suspensory agents usually used in the paints include bentonite, Fulbond No. 2, ball clay, core creams, dextrin, starch, sulphite lye, &c., but experimental work with other agents, such as artificial resins, is in progress.

A typical paint mixture which has been used in many of the foundry trials is :

Sillimanite or other paint base	100 lb.
Bentonite	2½ "
Core cream	5 "
Sulphite lye	2½ "
Water	8 gal.

In making this paint the bentonite was first stirred into about half the total volume of water and the paint base then added gradually with thorough stirring; the core cream and sulphite lye were then each stirred separately into one gallon of water and these were added to the paint-base/bentonite mix, the remainder of the water was added and the whole thoroughly stirred to a smooth emulsion. Fulbond may be used satisfactorily in place of bentonite, the weight used being increased to 3½ lb.

Paints have also been made using ball clay and dextrin in place of the bentonite, core cream and sulphite lye, a typical mixture being :

Paint base	100 lb.
Ball clay	15 "
Dextrin	2½ "
Water	8 gal.

The non-siliceous materials which have been used in foundry trials include Molochite (vitrified china clay), calcined aluminous fireclay (chamotte), sillimanite, calcined alumina, fused alumina or alundum, and zircon; all these were used in the "flour" condition, the specific surface being in the range of 2000 to 6000 sq. cm./g. The general conclusion from these trials is that it is quite practicable to eliminate silica flour from steel foundry mould and core paints.

The following is a general review of the foundry trials with the different non-siliceous materials.

Molochite.—This material is giving results at least equal to those obtained with silica paints on light- and medium-weight castings. On large and thick-walled castings the results reported are variable, but in general it is to be concluded that the results are not quite equal to those obtained with silica paint under the same conditions.

Calcined Aluminous Clay (Chamotte) is yielding results equal to those obtained with silica paint on medium-weight castings. One foundry reports that this material is now in regular and successful use on castings with a section up to 4 in., and that it has been found particularly satisfactory with manganese steel.

Sillimanite is giving satisfactory results in a number of foundries, but on heavy and thick-sectioned castings the results reported are erratic. One large foundry producing 500-lb. M.C. bombs has reported that "this material has now been in general use in the foundry for the past year, and results much better than those with silica flour are being obtained. The paint as used has a sp. gr. of 1.58." In this foundry the paint is prepared as follows: 3 cwt. of the sillimanite flour and 17 lb. of bentonite are intimately mixed dry; this mixture is added to 20 gal. of water and 27 quarts of paint cream (25 parts by weight of baltiseed cream mixed with 14 parts by weight of sulphite lye) and stirred into a creamy consistency. The mixture is then diluted to the desired specific gravity, which is adjusted to give ease of application with brushes and minimum settlement in the mixing tanks.

Fused Alumina.—From most of the trials with this material good results have been reported, but in one or two cases results below standard in stripping have been obtained. One foundry has reported a trial with pulverized scrap alundum grinding wheels: "After burning out the bond

and pulverizing, this material makes very successful paint, bonded either with oil or clay, and several good results have been obtained, notably on a coupling box of 6-in. section."

Zircon (Zirconium Silicate).—The foundry trials with this material are uniformly satisfactory; particularly good results have been obtained on dry-sand work, especially for cores surrounded by heavy metal sections. Information has been received that this material is giving highly satisfactory results in some American steel foundries.

The fusion points, by cone test, of the materials used in the trials are: Molochite 1710° C., calcined aluminous clay, 1720° C., sillimanite 1850° C., fused alumina 1960° C., and zircon 2100° C. That of typical silica flour is 1710–1720° C.

Trials have been made in several foundries with proprietary non-siliceous paints, with variable results. Steel-foundry trials with paints based on serpentine and mica have given unsatisfactory results, burning-on and bad stripping being reported; but it is likely that these materials would be suitable for iron and non-ferrous foundry use.

The conclusion from the foundry trials as a whole is that, from the technical viewpoint, one or other of the non-siliceous alternatives to silica will give quite satisfactory results in steel-foundry mould and core paints. Most of these materials are more costly than average silica flour, but there are definite indications from some of the trials that the increased cost is offset by improved results, particularly reductions in fettling costs.

THE HOT-STRENGTH CHARACTERISTICS OF MOULDING SANDS.*

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*Paper No. 15/1945 of the Steel Castings Research Committee (submitted by
the Moulding Materials Sub-Committee).*

SYNOPSIS.

This paper summarizes the results so far obtained in the research on the hot-strength characteristics of moulding sands which is in progress at Sheffield University. A description of the apparatus employed is given. Attention has so far been directed towards the differences between the hot-strength characteristics of the various clay bonds in relation to their mineralogical constitution. All the bonds so examined show a gradual increase in strength with rise of temperature. After a maximum strength is reached, the strength decreases rapidly. This peak hot strength is attained at a temperature of 900–1000° C. for clays having the silica-gibbsite-silica structure, *e.g.*, montmorillonite or secondary mica, and at a temperature of more than 1150° C. for clays having the silica-gibbsite, *i.e.*, kaolinite, structure.

I.—INTRODUCTION.

In recent years, investigators in the United States have paid attention to the strength of moulding materials at temperatures comparable with those attained in steel casting. Dunbeck¹ has given a brief account of the hot-strength characteristics of Western and Southern bentonites and of Ohio fireclay; he showed that certain fireclay-Western-bentonite mixtures have a higher hot strength than either of the two constituents, especially around 1000° C. Dietert and Curtis² have shown that the addition of silica flour to a moulding sand increases its hot strength considerably.

The first part of our investigation has been concerned with the hot-strength characteristics of various clay bonds in relation to their mineralogical constitution. The hot-strength characteristics of various clays were determined when used with Chelford sand to form a synthetic moulding sand. In addition, the hot-strength characteristics of several naturally-bonded moulding sands were investigated.

II.—THE DETERMINATION OF HOT STRENGTH.

(a) Apparatus.

Two types of compression machine were employed. The first was a lever-loading machine, in which the load was transmitted to the test-piece through a lever having a 4 : 1 ratio by a screw resting on a spring balance. The second was a modified Ridsdale hydraulic compression machine, in which the pillars were replaced by others arranged to carry the furnace. Two machines were found necessary owing to the wide variation in magnitude of the hot strength over the range of temperature employed. The lever machine was employed for strengths up to 400

* Received July 13, 1945. This paper is published by authority of the Steel Castings Research Committee. The views expressed in it are the authors', and are not necessarily endorsed by the Committee as a body.

lb./sq. in., while the hydraulic machine was used for strengths above 250 lb./sq. in.

The lever-loading machine is shown in Fig. 1; it consists of two pieces of angle steel bolted together to form the lever with a fulcrum of hardened steel fixed to this lever and resting in notches in a piece of hardened steel

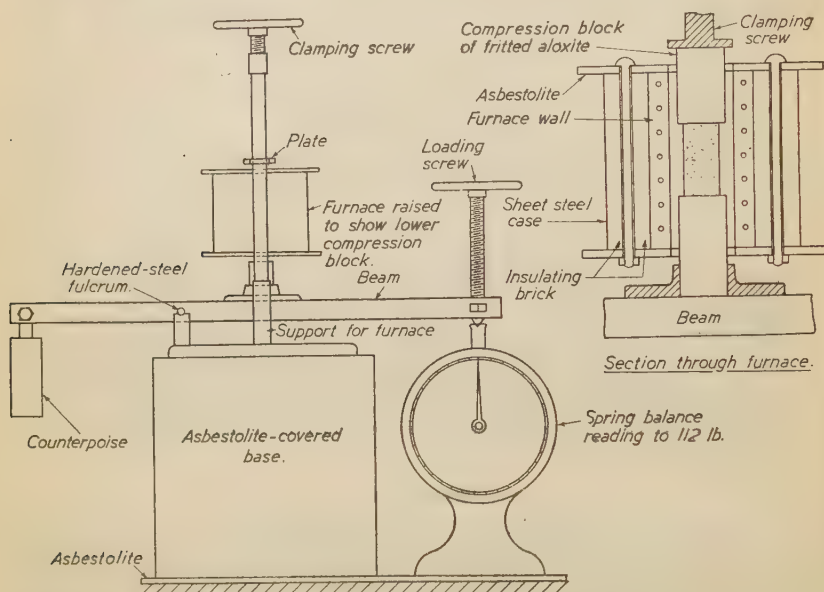


FIG. 1.—Hot-Strength Compression Machine.

attached to the base of the machine. A socket supporting a block of refractory material is attached to the lever a short distance from the fulcrum, and forms the lower compression plate of the machine. In the end of the lever on the same side as the socket is a nut through which a screw, fitted with a handle, passes and rests on the spring balance. A counterpoise is fitted to the other end of the lever, so that it is almost in balance. A B.C.I.R.A. test-piece (2.256×1.128 in.) rests on the refractory block. A second refractory block rests on the test-piece. Above this block is the upper compression plate, carried on a screw fitted with a handle; this screw passes through a cross-piece attached to two pillars bolted to the base of the machine. These pillars carry the furnace, and are long enough to permit the furnace to be raised for the insertion and removal of the test-piece.

The modified Ridsdale machine is shown in Fig. 2. The four pillars of the original machine were replaced by two steel pillars, 1 in. in dia., fixed at the diagonally opposite corners of the base. These pillars serve the same purpose as those in the lever machine, *i.e.*, they carry the furnace and the screw with the upper compression plate. The lower plate, comprising a socket and refractory block, was clamped to the piston of the Ridsdale machine; an asbestos disc was interposed between the socket and the piston, so as to avoid heating the oil in the cylinder. Essentially this modified machine was similar in arrangement to the lever-loading machine, but the pressure was applied directly by the Ridsdale machine instead of by a spring balance acting through a lever.

The refractory blocks were prepared from moistened mixtures of aloxite, or carborundum, with 2-3% of bentonite. They were shaped by ramming in a split core box $1\frac{1}{2}$ in. in internal dia., and, after drying slowly, they were fired at 1550°C . for 2 hr. in a gas-fired furnace. The resulting blocks were well fritted and mechanically strong.

The same furnace was used for both machines. The pillars of the machines passed through holes in the end-plates arranged so that the axis of the furnace coincided with the compression axis of the machine. The furnace winding was built on the "coiled-coil" principle, and was constructed from Bright-ray wire of No. 17 S.W.G., with an overall resistance of $19\ \Omega$. The wire was made into a coil by winding round a $\frac{1}{2}$ -in. dia. bar held in a lathe; this coil was then wrapped around a wood or cardboard former 2 in. in dia. The winding was embedded in a paste of powdered sillimanite and water; it was found advisable to double the wire where it is exposed at the ends of winding, so as to minimize oxidation in service. After drying slowly, the winding was placed in a muffle and the wood or cardboard former burnt out; exposed wire on the inside of the winding was then coated with the sillimanite paste. After again drying slowly, the winding was baked once more in the muffle at $700\text{--}800^{\circ}\text{C}$. A winding of this type reduces the temperature drop between the wire and the test-piece to a minimum, and consequently the test-piece can be heated to a temperature close to the safe limit of the wire. As the winding is totally enclosed, oxidation is reduced to a minimum. The furnace must not be heated above 1150°C ., or it will fail quickly.

The furnace is heated by a single-phase transformer supplied from the 200-V. A.C. mains. The transformer has tapings in 25-V. steps from 25 to 200 V., with a maximum current of 10 amp. at any voltage. Lead wire fuses were fitted on both sides of the transformer to avoid damage to it in case of mishap.*

* After the present investigation had been almost completed, a Dietert hot-strength machine (or dilatometer) was imported into this country by Messrs. Hopkinson's, Ltd., of Huddersfield. The maximum safe working temperature of this machine is some $200\text{--}250^{\circ}\text{C}$. higher than that of the apparatus at Sheffield. Messrs. Hopkinson's very kindly allowed us to use this machine in order both to compare results within the range of the Sheffield apparatus and to extend our investigations to higher temperatures. Reasonably good agreement was found between results obtained with the two sets of apparatus; the extended results are included in this paper.

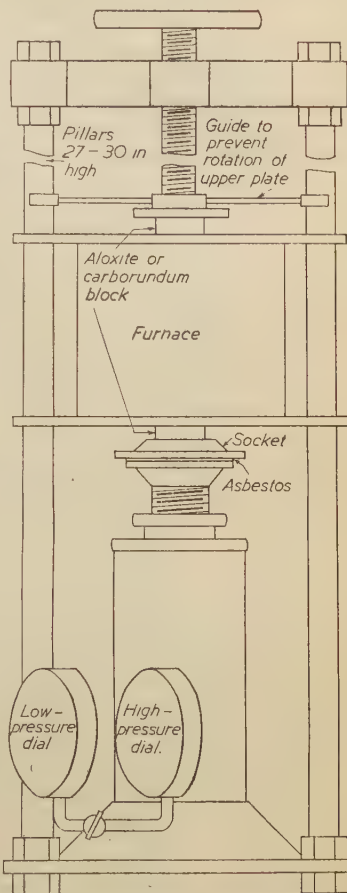


FIG. 2.—The Modified Ridsdale Machine.
One-sixth actual size.

(b) Procedure.

Throughout the research, B.C.I.R.A. test-pieces were prepared by ramming under the standard A.F.A. rammer; five blows were given to each end of the core box, the blows being alternately on one end and the other. The test-pieces were dried at 200°C . in a Hearson thermostatically-controlled oven. The B.C.I.R.A. test-piece (2.256×1.128 in.) was adopted in preference to the A.F.A. test-piece (2.0×2.0 in.), so that the temperature difference between the interior and exterior of the test-piece should be as low as possible.

The methods of testing in the two machines differed only in minor details. A spare test-piece left over from a previous series of tests was

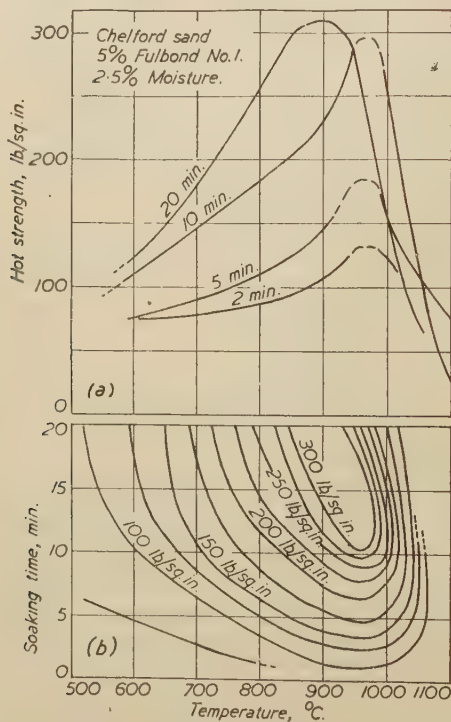


FIG. 3.—Hot-Strength Characteristics of a Synthetic Sand.

placed in the furnace, together with the upper refractory block; the furnace was then raised to the required temperature and the voltage adjusted so that the temperature was steady. The temperature was measured by means of a platinum/platinum-rhodium thermocouple level with the middle of the test-piece. The upper plate was raised by the screw to its highest position and the upper block removed to a sand tray. The furnace was then raised and the test-piece removed. A new test-piece was inserted and the furnace lowered. The upper block was replaced and the time noted. The upper plate was then screwed down, care being taken to see that it rested squarely on the upper block; in the lever machine, the screw over the compression balance had to be adjusted slightly to

achieve this. After a specified time, the test-piece was crushed by raising the lower plate, either by pumping up the piston of the Ridsdale machine or by turning the screw above the compression balance in the lever machine. It was found desirable to fit a tinplate tray (not shown in Figs. 1 and 2) just below the lower block, so as to catch the fragments of the test-piece when the furnace was raised to insert a fresh test-piece.

III.—THE GRAPHICAL EXPRESSION OF HOT STRENGTH.

Both time and temperature are involved in the expression of hot strength, as there is a considerable lag before the test-piece is heated throughout. If a test-piece is crushed after waiting for, say, half a minute, its interior is still cold and the strength is only slightly higher than that of an unheated test-piece. As the period of heating is increased, the test-piece is heated more thoroughly and the strength increases.

Consequently the hot-strength characteristics of a moulding material are conveniently represented by contour graphs, indicating the temperature, the time of heating, and the hot strength simultaneously. In Fig. 3 (a) curves are drawn for various periods of heating to show the relationship of hot strength to temperature for a synthetic moulding sand. In all these curves the hot strength increases with rise of temperature to a maximum value and then decreases sharply. Fig. 3 (b), derived from Fig. 3 (a), shows the hot strength as contours in relation to temperature and time of heating; thus the contour for 150 lb./sq. in. shows that the test-piece will attain this hot strength if heated for 20 min. at 650° C. or for 5 min. at 850° C. The peak value of more than 300 lb./sq. in. is attained for only a limited range of temperature, and after a certain period of heating; in this instance, the peak value is attained at 925° C. after heating for 12 min., and at a slightly lower temperature if the period of heating is increased.

IV.—THE CLAY MINERALS.

Three principal groups of clay minerals have been recognized by clay mineralogists.* They are the kaolinite, montmorillonite, and secondary mica (including illite) groups. The structural unit of the kaolinite group is composed of a layer of hydrated alumina (gibbsite) attached to a silica layer and is known as the kaolinite unit; china clay, ball clays, and true fireclays are composed principally of kaolinite. The structural unit of the montmorillonite and secondary mica groups is composed of one gibbsite layer between two silica layers; montmorillonite is the principal constituent of fuller's earth and bentonite, while the secondary micas form the typical bond of the "rotten-rock" moulding sands of Durham and the Midland Valley of Scotland.

V.—THE HOT-STRENGTH CHARACTERISTICS OF THE MONTMORILLONITE CLAYS.

The hot-strength characteristics of three montmorillonite clays were determined; the clays were:

Wyoming Bentonite—composed mainly of sodium montmorillonite.

Fulbond No. 1—Fuller's earth composed mainly of calcium montmorillonite.

Fulbond No. 3—Similar to Fulbond No. 1, but treated with sodium carbonate to convert the calcium montmorillonite to sodium montmorillonite.

In each case Chelford sand was bonded with 5.0% of one of these clays and either 2.5% or 5.0% of moisture.

* See W. Davies, "The Fundamental Characteristics of Moulding Materials" (*Journal of The Iron and Steel Institute*, in the press) for detailed account of clay minerals.

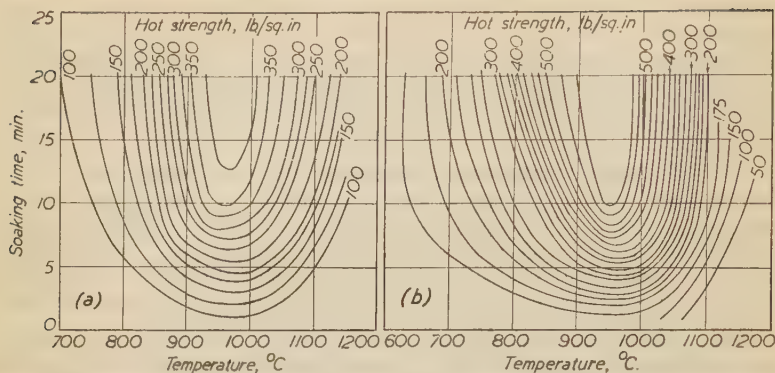


FIG. 4.—Hot-Strength Characteristics of Chelford Sand Bonded with 5.0% of Bentonite (a) at 2.5% and (b) at 5.0% of original moisture. B.C.I.R.A. test-pieces.

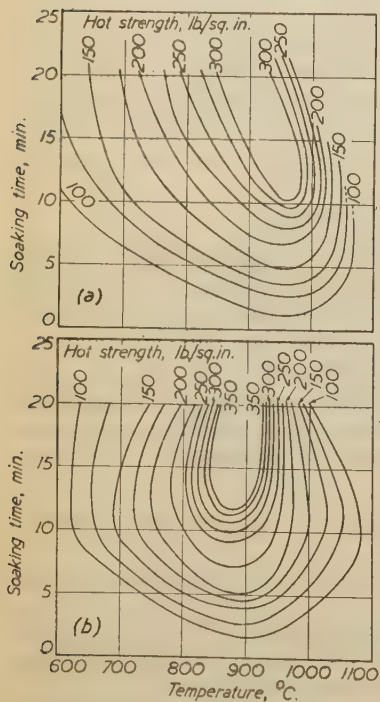


FIG. 5.—Hot-Strength Characteristics of Chelford Sand Bonded with 5.0% of Fulbond No. 1 (a) at 2.5% and (b) at 5.0% of original moisture. B.C.I.R.A. test-pieces.

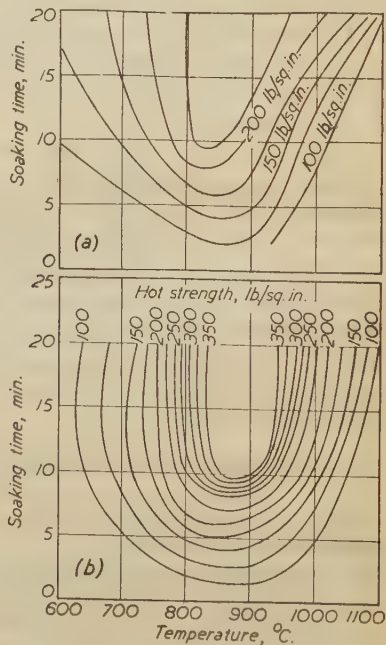


FIG. 6.—Hot-Strength Characteristics of Chelford Sand Bonded with 5.0% of Fulbond No. 3 (a) at 2.5% and (b) at 5.0% of original moisture. B.C.I.R.A. test-pieces.

The curves for Wyoming bentonite are shown in Fig. 4 (a) and (b). It will be seen that the peak hot strength is attained at 950°C . and that the temperature at which the peak strength is reached is but slightly affected by the original moisture content of the test-pieces. The hot strength is increased by increasing the original moisture content.

The curves for Fulbond No. 1 are shown in Fig. 5 (a) and (b). The peak hot strength is attained at $875\text{--}925^{\circ}\text{C}$., depending on the moisture content and, in the case of the drier mix, on the period of heating. The hot strength is increased slightly by increasing the original moisture content.

The curves for Fulbond No. 3 are shown in Fig. 6 (a) and (b) and are closely similar to those for Fulbond No. 1.

VI.—THE HOT-STRENGTH CHARACTERISTICS OF THE SECONDARY MICA CLAYS.

The hot-strength characteristics of two naturally bonded, crushed sandstones were determined; they were:

“Rotten-rock” moulding sand from Viewly Hill Quarry, Tow Law, Co. Durham. (W7 in Part 9 of “British Resources of Steel Moulding Sands.” *)
Mansfield moulding sand.

Both these moulding sands are prepared by crushing and milling soft sandstones. Both are naturally bonded by secondary mica; in the Tow Law sand, this is of the hydrobiotite type, while in the Mansfield sand it is of the sericite type.

The curves for the Tow Law sand are shown in Fig. 7 (a) and (b). It will be seen that the peak hot strength is attained at 1000°C . and that the peak hot strength is increased by increasing the original moisture content.

The curves for the Mansfield sand are shown in Fig. 8. They are similar to those for the Tow Law sand, but the peak hot strength is attained at 975°C .

VII.—THE HOT-STRENGTH CHARACTERISTICS OF THE KAOLINITE CLAYS.

Owing to the temperature limit of the furnace, it was not possible to investigate the hot-strength characteristics of these clays completely. The clays examined were:

China clay.
Powdered ball clay.
Powdered aluminous fireclay.

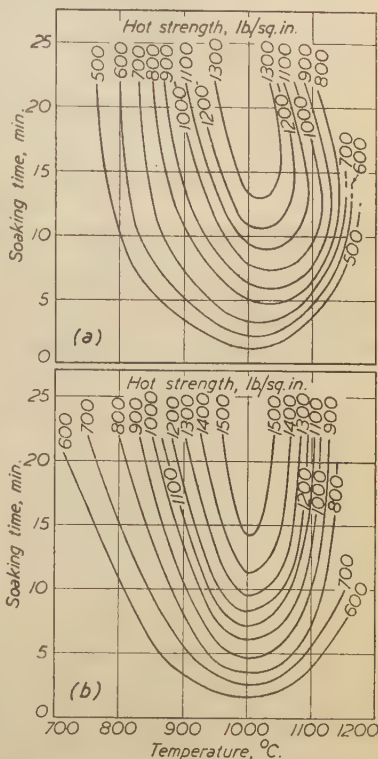


FIG. 7.—Hot-Strength Characteristics of Tow Law Sand with (a) 6.0% and (b) 10.0% of original moisture.

* W. Davies and W. J. Rees, *Journal of The Iron and Steel Institute*, 1945, No. II., pp. 71 P–116 P.

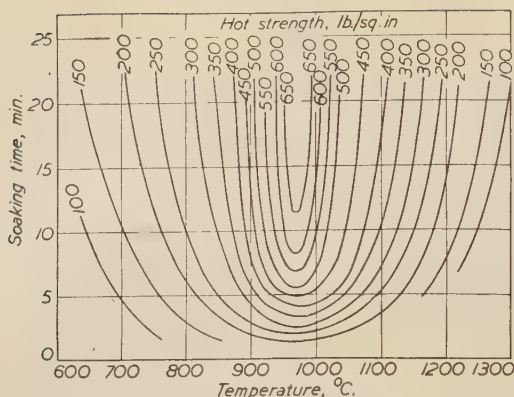


FIG. 8.—Hot-Strength Characteristics of Mansfield Sand having 7% of original moisture.

In each case Chelford sand was bonded with 7.5% of the clay and 3.5% moisture. The curves are shown in Figs. 9–11. The china clay mix attained its peak hot strength at 1250° C., while the mixes bonded with ball clay and fireclay attained their peak hot strengths at 1140° C. This is

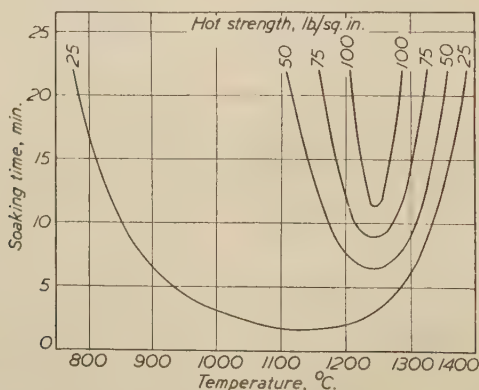


FIG. 9.—Hot-Strength Characteristics of Chelford Sand Bonded with 7.5% of China Clay. Original moisture content = 3.5%.

to be expected for the ball clay and fireclay contain sericite as well as kaolinite, while the china clay is composed of almost pure kaolinite.

VIII.—CONCLUSIONS.

The data already obtained indicate that there are important differences in the behaviour of clay bonds at high temperatures. The montmorillonite and secondary mica clays, having similar atomic structures, attain their peak hot strengths at 900–1000° C.; above 1100° C. their hot strength is quite low. The kaolinite clays, on the other hand, attain their peak hot strength at temperatures above 1150° C.

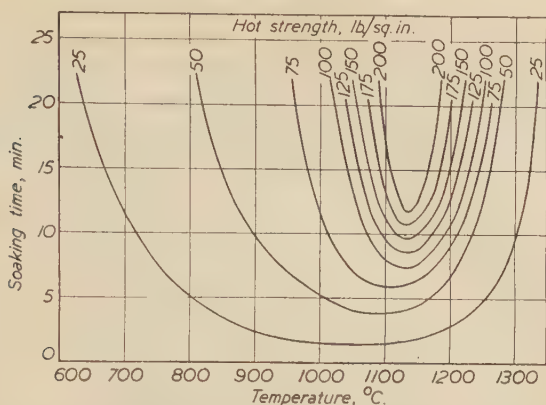


FIG. 10.—Hot-Strength Characteristics of Chelford Sand Bonded with 7.5% of Ball Clay. Original moisture content = 3.5%.

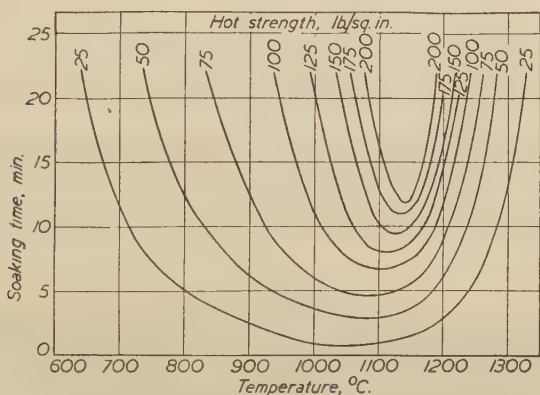


FIG. 11.—Hot-Strength Characteristics of Chelford Sand Bonded with 7.5% of Fireclay. Original moisture content = 3.5%.

These differences are in accord with foundry practice. Moulds for large castings are usually prepared from materials containing a considerable proportion of fireclay, *e.g.* "compo." Furthermore, compo is frequently employed in smaller moulds at those points where the wash of molten metal is most severe, as, for instance, in the vicinity of the runner.

ADDENDUM.—*The Hot Strength of Moulding Sands below 600° C.*

After reading the proofs, Mr. Basil Gray indicated that in dry-sand moulding a better casting finish is obtained if the moulds are closed and cast as quickly as possible after leaving the drying stove, than if pouring is delayed until the moulds have cooled. The probable explanation is a two-fold one, and can be seen from the curves in Fig. 12: from 200° to 600° C., that is, within the range of most drying stoves, the hot strength

increases, in this instance from about 70 to 120 lb./sq. in. If, on the other hand, the test-pieces are cooled to room temperature in a desiccator before crushing, the cold dry strength shows a progressive decrease from 33 lb./sq. in. for test-pieces cooled from 200° C. to 8 lb./sq. in. for test-pieces cooled from 600° C. This effect is even more marked if the test-pieces are exposed to the atmosphere during cooling, because of moisture absorption. Though the curves given are for Chelford sand bonded with

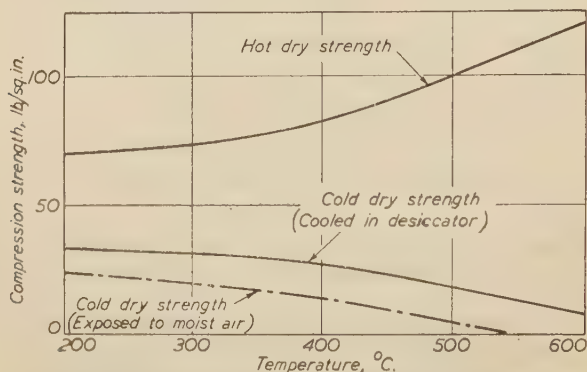


FIG. 12.—Hot and Cold Dry Strength Characteristics of a Synthetic Sand. (Chelford sand bonded with 5% of Fulbond No. 1 and 3.5% of moisture.) Soaking time = 2 hr.

5% of Fulbond No. 1 and 3.5% of moisture, similar curves apply to sands bonded with other types of clay.

These curves indicate that a high drying temperature is an advantage only if the moulds are closed and cast as quickly as possible after removal from the stove.

REFERENCES.

1. N. J. DUNBECK : *Proceedings of the Institute of British Foundrymen*, 1940-41, vol. 34, pp. 17-34 (see especially Table V.).
2. H. W. DIETERT and G. CURTIS : *Foundry*, 1941, vol. 69, No. 9, p. 58.

For Correspondence on this Paper see the *Journal*, 1946, No. 1.

BRITISH RESOURCES OF STEEL MOULDING SANDS.—PARTS 6 TO 10.*

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(Figs. 85 to 105 = Plates VII. to X.)

Paper No. 16/1945 of the Steel Castings Research Committee (submitted by the Moulding Materials Sub-Committee).

GENERAL INTRODUCTION.

PARTS 1 to 5 of this paper were published in the *Journal of The Iron and Steel Institute*, 1943, No. II, pp. 11 P–111 P. For convenience, the illustrations and Tables in Parts 6 to 10 are numbered consecutively with those of the earlier Parts.

Part 6.—The Sand Deposits Associated with the Lincolnshire Wolds.

(Figs. 85 and 86 = Plate VII.)

SYNOPSIS.

These sands occur within easy reach of the foundries of Yorkshire, Derbyshire, and Nottinghamshire. The sands may be divided into two groups: those of Recent age and those of the Lower Cretaceous age. Both types are suitable for use as silica sands; those of Recent age are similar to the sands of Southport and Chelford, while those of Lower Cretaceous age resemble certain of the Leighton Buzzard sands.

I.—INTRODUCTION.

THE sand deposits which occur along the scarp (or western) face of the Lincolnshire Wolds are of interest as sources of high-silica sand readily accessible to the foundries of the Yorkshire, Derbyshire, and Nottinghamshire coalfields. As will be seen from the sketch map, Fig. 71(a), the localities from which the samples were obtained lie a short distance to the east of the railway connecting Lincoln, Market Rasen, and Scunthorpe.

Two types of sand deposit can be distinguished, *viz.*, those of Recent age and those of Lower Cretaceous age. Their relationships are illustrated by Fig. 71(b). The crest of the Wolds is formed by the Chalk, underneath which is a thin group of Lower Cretaceous beds; these have been subdivided by the Geological Survey † as follows:

Tealby limestone	0–14 ft.
Tealby clay	0–40 ft.
Claxby ironstone	0–14 ft.
Spilsby sandstone	0–80 ft.

The Spilsby sandstone forms the first type of sand deposit. The second type of sand deposit is composed of blown sand, which has accumulated in

* Received July 13, 1945. This paper is published by authority of the Steel Castings Research Committee. The views expressed in it are the authors', and are not necessarily endorsed by the Committee as a body.

† "Special Reports on the Mineral Resources of Great Britain." Vol. XII.—"Bedded Iron Ores," 1920, p. 211 *et seq.*

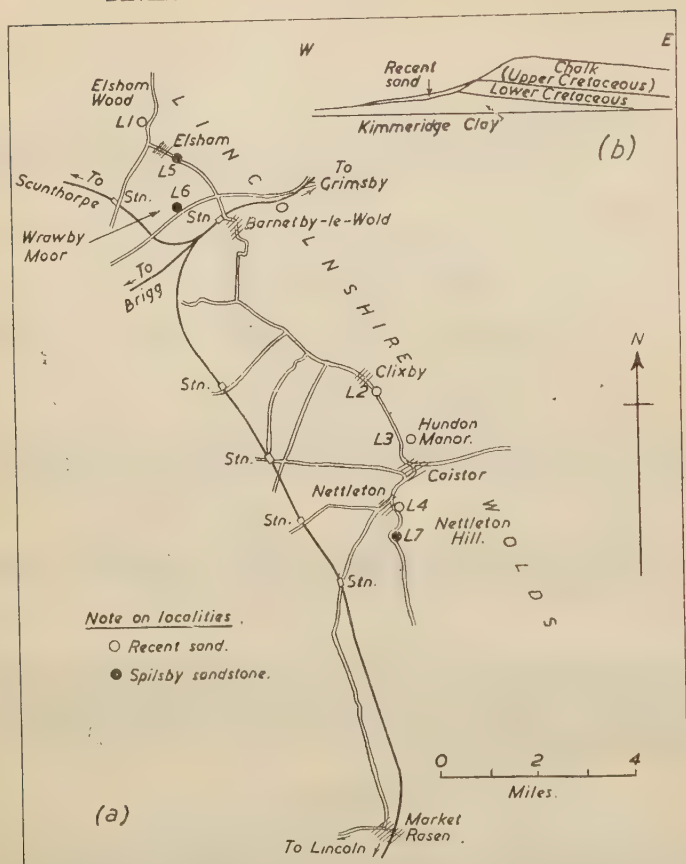


FIG. 71.—The Sand Deposits Associated with the Lincolnshire Wolds. (a) Sketch-map of the localities examined. (b) Section across the Wolds.

Recent times against the scarp face, and partly fills some of the narrow valleys which notch the scarp.

The localities from which the samples were obtained are given in Table XXXVIII.

TABLE XXXVIII.—Index to Samples.

Ref. No.	Locality.
<i>Recent Sands.</i>	
L1	Elsham Wood; $\frac{3}{4}$ mile north-west of Elsham.
L2	Clixby; adjoining main road $\frac{1}{4}$ mile south-south-east of Clixby.
L3	Hundon Manor; $\frac{1}{2}$ mile north of Caistor.
L4	Nettleton Village; adjoining by-road to Nettleton Hill.
<i>Spilsby Sandstone.</i>	
L5	Elsham Village; adjoining Elsham-Barnetby Road.
L6	Wrawby Moor; adjoining main road $1\frac{1}{2}$ miles west-north-west of Barnetby.
L7	Nettleton Hill; adjoining by-road to Nettleton Hill.

II.—THE RECENT SANDS.

(a) *Petrology.*

These wind-blown sands are fine-grained. Their colour varies from light to dark brown, depending on the amount of limonite and vegetable matter. The quartz grains are subangular and are slightly coated with limonite and clay; this coating imparts a dusty appearance to sands L1 and L2. Small fragments of chalk, probably derived from the adjacent scarp, and particles of shale occur at some localities. Grains typical of these sands are shown in Fig. 85.

(b) *Chemical Analyses.*

The chemical analyses of the sands are given in Table XXXIX., together with representative analyses of Chelford and Southport sands for

TABLE XXXIX.—*Chemical Analyses of the Recent Sands.*

	L1.	L2.	L3.	L4.	Chelford.	Southport.
SiO ₂ , %	93.30	95.08	94.29	94.68	97.13	93.40
TiO ₂ , %	0.09	0.10	0.14	0.10	0.02	0.14
Fe ₂ O ₃ , %	0.56	1.00	1.00	2.13	0.11	0.62
Al ₂ O ₃ , %	0.65	0.90	0.82	1.75	1.48	3.35
CaO, %	1.60	0.76	0.26	0.18	0.14	0.76
MgO, %	0.22	0.22	0.30	0.06	0.18	0.42
K ₂ O, %	0.35	0.43	0.38	0.18	0.38	0.33
Loss on ignition, %	3.19	1.46	0.77	0.88	0.50	0.92
Total	99.96	99.95	99.96	99.96	99.94	99.94

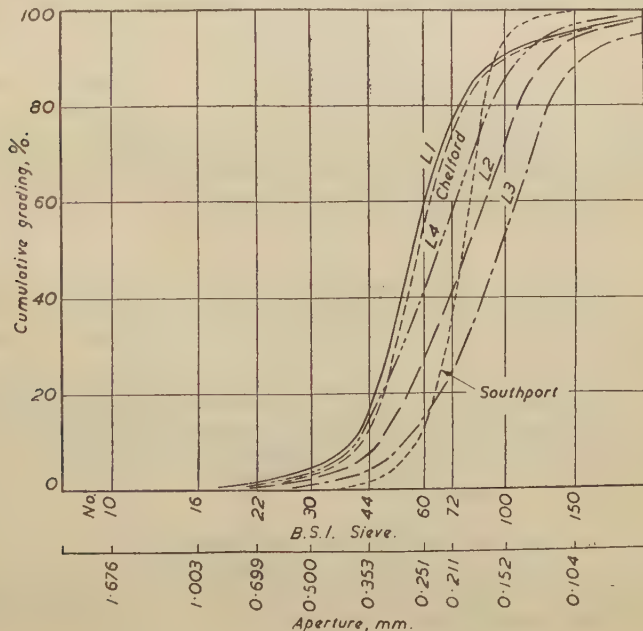


FIG. 72.—Mechanical Gradings of the Recent Sands.

comparison. It will be seen that the lime content of sands *L1* and *L2* is high, principally because of the numerous chalk fragments in these two sands. The alkali content is low, while the silica content is fairly high.

(c) *Physical Characteristics.*

The physical characteristics are summarized in Table XL.; the corresponding data for Chelford and Southport sands are included for com-

TABLE XL.—*The Physical Characteristics of the Recent Sands.*

Percentage Retained on B.S.I. Sieve No.—	<i>L1.</i>	<i>L2.</i>	<i>L3.</i>	<i>L4.</i>	Chelford.	Southport.
<i>Mechanical Grading.</i>						
5	0.0	0.0	0.0	0.0	0.0	0.0
8	0.6	0.0	0.2	0.2	0.0	0.0
10	0.5	0.0	0.0	0.1	0.0	0.0
16	0.9	0.1	0.2	0.6	0.3	0.1
22	0.3	0.3	0.2	1.2	0.6	0.1
30	1.8	1.8	0.7	3.9	2.6	0.1
44	10.2	5.8	2.4	8.4	11.5	0.1
60	44.4	22.2	12.5	30.4	43.7	12.7
72	13.2	11.6	8.6	12.5	12.0	20.4
100	19.3	29.1	27.7	26.9	18.5	61.0
150	6.4	23.4	35.2	13.2	7.5	5.4
Pass 150	2.3	5.9	12.5	2.5	3.3	0.2
Total	99.9	100.2	100.2	99.9	100.0	100.1
Maximum packing density, g./c.c.	1.54	1.63	1.66	1.70	1.63	1.66
Specific surface, sq. cm./g..	120.28	165.66	161.86	116.60	125.7	125.20
Average coeff. of angularity	1.13	1.15	1.14	1.11	1.09	1.06
<i>Refractoriness.</i>						
A.F.A. test-pieces rammed 10 times, bonded with 5.0% of Fulbond No. 1; fired at 1550° C. for 2 hr.						
<i>L1</i> : White; grains fritted together; expansion 2.5%.						
<i>L2</i> : White; with dark-brown mottling; surface glazed; shrinkage 10.0%.						
<i>L3</i> : White; with dark-brown mottling; surface glazed; shrinkage 10.0%.						
<i>L4</i> : Brown mottled; surface glazed; test-piece distorted.						
Chelford : White; grains slightly fritted; expansion 5.0%.						
Southport : White; with slight brown mottling; grains well fritted together; shrinkage 2.5%.						

parison. The cumulative grading curves are given in Fig. 72. It will be seen that sand *L1* is comparable with Chelford sand, while sands *L2*, *L3*, and *L4* resemble more closely Southport sand, though they are not so well graded.

The low maximum bulk density of sand *L1* is due to its rather high content of vegetable matter. Sand *L2* contains more clay than the other Recent sands, and consequently there is a greater difference between the specific surface of the sand and that of sand grade only, than for the other sands. The average coefficients of angularity range from 1.11 to 1.14, that is, the grains are subangular.

III.—THE SPILSBY SANDSTONE.

Though this bed is referred to as a sandstone, in most quarry exposures it is as free as the high-silica sands of Chelford and Leighton Buzzard. Locally it may contain sufficient calcite cement to justify the term "sand-

stone." The outcrop is discontinuous. In the northern outcrop, between Elsham and Barnetby, the sandstone is present as a small lens, having a maximum thickness of 20–30 ft. In the southern outcrop the sandstone appears near Clixby and increases in thickness until at Donnington-on-Bain, south-east of the area examined, it attains a thickness of 80 ft.

(a) *Petrology.*

Sands from the northern outcrop are well graded and vary from white to pale brown in colour. Those from the southern outcrop are badly graded, frequently including small pebbles, and are pale green in mass.

TABLE XLI.—*Chemical Analyses of the Spilsby Sandstone.*

	L6.	L7.	Leighton Buzzard No. 52.
SiO ₂ , %	98.19	95.00	98.75
TiO ₂ , %	0.12	0.08	0.02
Fe ₂ O ₃ , %	0.40	0.70	0.16
Al ₂ O ₃ , %	0.39	1.01	0.47
CaO, %	0.08	1.73	0.12
MgO, %	0.14	0.20	0.08
K ₂ O, %	0.20	0.21	0.14
Loss on ignition, % .	0.46	1.05	0.20
Total	99.98	99.98	99.94

TABLE XLII.—*The Physical Characteristics of the Spilsby Sandstone.*

Percentage Retained on B.S.I. Sieve No.—	L5.	L6.	L7.	Leighton Buzzard No. 52.
<i>Mechanical Grading.</i>				
5	0.0	0.0	0.9	0.0
8	0.1	0.2	2.2	0.0
10	0.1	0.1	1.3	0.0
16	0.1	0.2	14.6	2.5
22	0.2	0.4	14.0	5.9
30	1.6	5.0	17.9	19.7
44	30.9	27.7	16.8	49.8
60	61.8	56.2	15.5	20.9
72	3.6	5.2	5.0	0.9
100	1.2	3.8	9.2	0.1
150	0.3	0.8	2.1	0.2
Pass 150	0.1	0.4	0.4	0.1
Total	100.0	100.0	99.9	100.1
Maximum packing density, g./c.c. .	1.60	1.60	1.74	1.63
Specific surface, sq. cm./g. . . .	80.91	89.48	67.72	57.17
Average coeff. of angularity . . .	1.11	1.10	1.11	1.06

Refractoriness.

A.F.A. test-pieces rammed 10 times, bonded 5.0% of Fulbond No. 1; fired at 1550° C. for 2 hr.

L5: White, grains just fritted together; expansion 5.0%.

L6: White, with brown mottling; grains fritted together; expansion 5.0%.

L7: White, with slight brown mottling; grains just fritted together; expansion 6.0%.

Leighton Buzzard No. 52: White; grains just fritted together; expansion 5.0%.

The quartz grains are subangular and are slightly coated with limonite and clay. Grains typical of these sands are shown in Fig. 86. Sand *L6* contains lumps of clay an inch or more across, which could readily be removed by hand screening; they were removed from the sample before the examination of its physical characteristics.

(b) *Chemical Analyses.*

The chemical analyses of these sands are given in Table XLI., together with that of a sample of Leighton Buzzard No. 52 sand for comparison.

It will be seen that sand *L6* compares favourably with the Leighton Buzzard sand. Sand *L7* is slightly bonded with clay and calcite.

(c) *Physical Characteristics.*

The physical characteristics are summarized in Table XLII.; the corresponding data for Leighton Buzzard No. 52 sand are included for comparison. As will be seen from the cumulative grading curves, Fig. 73,

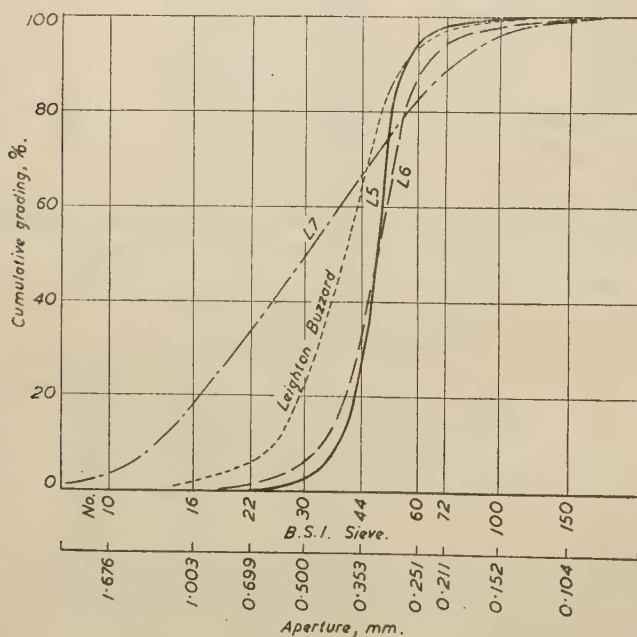


FIG. 73.—Mechanical Gradings of the Spilsby Sandstone.

sands *L5* and *L6* are as well graded as the Leighton Buzzard sand; sand *L7* is badly graded. The grains of sands *L5-7* are not quite so rounded as those of Leighton Buzzard sand.

APPENDIX.—*Details of Localities.*

Recent Sand.

L1 Elsham Wood.—Adjoining road $\frac{3}{4}$ mile north-west of Elsham. This is a long-disused small sand pit, situated $1\frac{3}{4}$ miles by road from

Elsham Station. The sand is brown and has a dusty appearance. As the exposures were shallow the sample was rather contaminated with vegetable matter. Fragments of chalk are not uncommon.

L2 Clixby.—Adjoining main road $\frac{1}{4}$ mile south-south-east of Clixby. This is a roadside exposure $3\frac{1}{2}$ miles by road from the nearest station. This sand is similar to L1, but contains less chalk and vegetable matter.

L3 Hundon Manor.—Adjoining farm road $\frac{1}{2}$ mile north of Caistor. Sand quarry worked by J. W. Hardiss, Hillcrest Garage, Caistor, and situated 3 miles by road from the nearest station. This quarry is cutting into the side of a small valley, so that the face is wedge-shaped and has a maximum height of 30 ft. It is worked by means of a Diesel-driven excavator; the sand is at present being used for concrete work. The sand is pale brown in mass; unlike L1 and L2, it is not dusty, nor does it contain vegetable matter or chalk.

L4 Nettleton Village.—Adjoining by-road to Nettleton Hill. This sand quarry is handworked by J. Harwood, Nettleton, and is situated $2\frac{1}{2}$ miles by road from the nearest station. This sand resembles L1, but contains layers rich in chalk fragments.

Spilsby Sandstone.

L5 Elsham Village.—Sample from exposure adjoining the Elsham-Barnetby road. This locality is 2 miles by road from Elsham station. This sand is poorly exposed. It is a particularly clean, white sand.

L6 Wrawby Moor.—Adjoining main road, $1\frac{1}{4}$ miles west-north-west of Barnetby. This quarry is worked for Aylesby Gravels, Town Hall Street, Grimsby, and is situated $1\frac{1}{4}$ miles by road from Barnetby station. The upper part of the quarry is composed of sand and flint, probably of glacial origin; the lower part is composed of Spilsby sandstone and is being handworked for sand for concrete work. The sand includes lumps of clay an inch or more across which could readily be removed by hand screening. The base of the sandstone has not been exposed, but the thickness probably exceeds 10 ft. The sand is pale brown in mass.

L7 Nettleton Hill.—Adjoining by-road. Sand quarry worked by S. L. Goldthorpe, 405, Victoria Street, Grimsby, and situated 3 miles by road from the nearest station. This is a small, hand-worked quarry, in which 2-3 ft. of overburden overlies 6 ft. of badly graded sand. The sand is pale green in mass and contains grains of a compact dark material. The sand passes down into calcareous sandstone.

Part 7.—The Quartzitic Grits and Sandstones of Nidderdale and Wharfedale.

(Figs. 87 and 88 = Plate VII.)

SYNOPSIS.

The beds of friable, white quartzitic sandstone which are exposed in the vicinity of Nidderdale and Wharfedale are of interest as a source of high-silica sand. They are fairly close to the foundries of Yorkshire and Tees-side. The physical characteristics of the crushed sandstones vary along the outcrops; at some exposures the gradings are comparable with those of certain of the Leighton Buzzard sands, while at others they resemble that of Chelford sand.

I.—INTRODUCTION.

THE Millstone Grit Series in the country around Nidderdale and Wharfedale is composed of alternate beds of sandstone and shale. The Geological Survey * have defined several of the prominent sandstone beds near the

* Geological Survey, Old Series, One-Inch Sheet. 92 N.E.

base of the Series as the Kinderscout Grits. Near the middle of the Series is a prominent fossil band known as the Cayton Gill Shell Bed. The sandstone beds between the Shell Bed and the Kinderscout Grits are unnamed; they may be described as quartzitic sandstones, for, unlike the typical sandstones of the Series, they contain little or no clay bond and rarely do they contain any felspar. The occurrence of white siliceous grits at several horizons in the Millstone Grit Series in the country to the south is mentioned by the Geological Survey.*

Samples of these quartzitic sandstones were obtained from the two localities indicated on the sketch-map (Fig. 74). These localities are typical of the quartzitic sandstone exposures in this district.

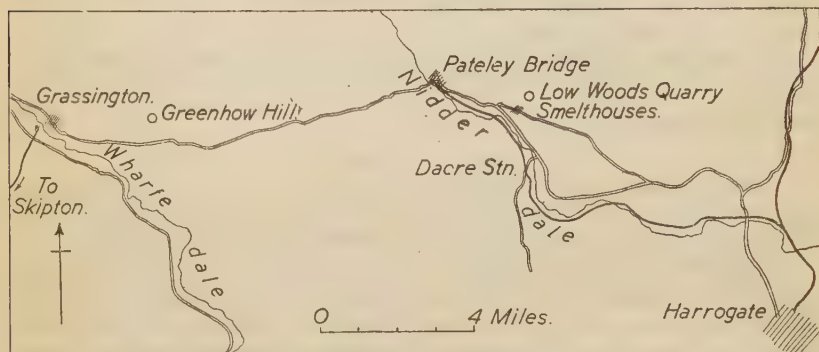


FIG. 74.—Localities Examined in Wharfedale and Nidderdale.

II.—THE QUARTZITIC SANDSTONE AT LOW WOODS QUARRY, SMELTHOUSES.

(a) *Geology.*

This outcrop is bounded on all sides but the south by a thin bed of shale succeeded by the Shell Bed, as will be seen from Fig. 75(a). On the south it is bounded by a series of faults having throws of 50–100 ft.

Since the typical Millstone Grit of this area is felspathic, the occurrence of a sandstone composed almost entirely of quartz is remarkable. It may be due to the presence of vegetable matter when the sand was being deposited. The only evidence in favour of this suggestion is the occurrence of a thin coal immediately below the sandstone. In the country to the south, the Geological Survey (*loc. cit.*) mention the occurrence of thin inferior coals at various horizons in this Series.

The detailed structure of the white quartzitic sandstone bed is shown in Fig. 75(b). It is exposed in several small crags overlooking a small stream. No section of fresh unweathered rock is available. The sandstone is false-bedded: four major lenses or lenticular beds may be distinguished in the crags.

(i) *The Coarse White Grit.*—The lowest bed is composed of coarse, white grit and rests on the thin coal; this bed is shown in Fig. 75(b). The total thickness of this grit at C is 30–35 ft., of which 15–20 ft. is exposed in an old shaft, the top of which is at river level. Thin sections of this grit show that it is composed of large, corroded quartz grains, with a small

* Memoir for Geological Survey, Old Series, One-Inch Sheet. 92 S.E.

See also K. C. Dunham and C. J. Stubblefield, *Quarterly Journal of the Geological Society*, 1944, vol. 100, pp. 209, *et seq.*

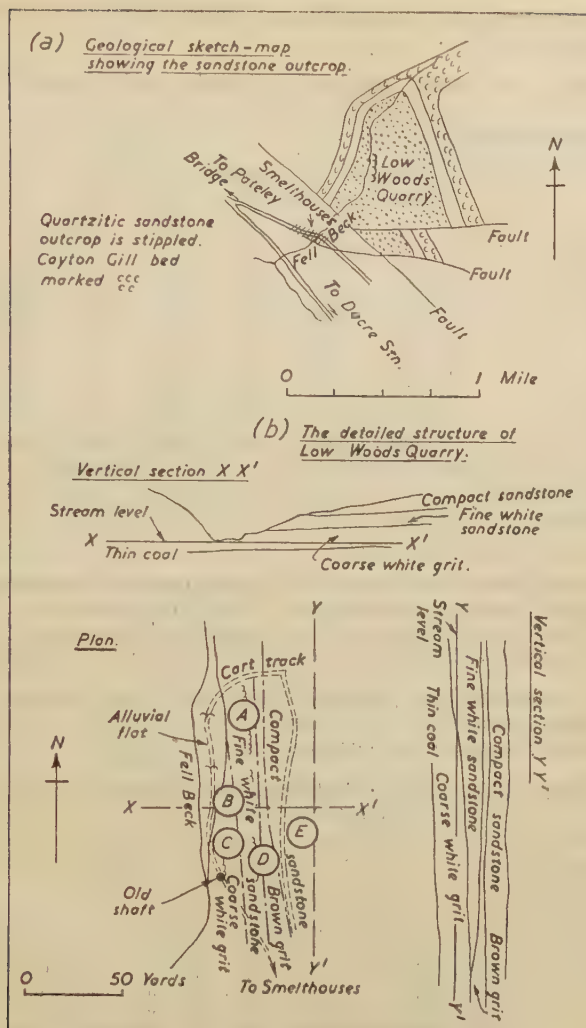


FIG. 75.—The Geology of Low Woods Quarry, Smelthouses.

proportion of kaolinite, which is interstitial to the quartz grains. Some of the grains show signs of strain and have cracked along the plane of weakness, probably as a result of frost action. Grains of quartzite are rare. Sericite is associated with some of the interstitial kaolinite. As will be seen from Fig. 87 the texture is open, and there is little suturing of the quartz grains; consequently the rock is quite friable. Facets are developed on some of the quartz grains.

This major lenticular bed of coarse white grit is itself built up of minor lenses, the mechanical gradings of which differ slightly. The extent of this

variation is illustrated by the gradings of samples from localities *B* and *C* shown in Table XLIII.

TABLE XLIII.—*Mechanical Gradings of Samples of the Coarse White Grit.*

Percentage Retained on B.S.I. Sieve No.—	Locality <i>B</i> .	Locality <i>C</i> .						
5	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
8	0.1	1.0	0.1	0.3	0.0	0.0	0.0	0.2
10	0.2	1.2	0.1	0.1	0.0	0.0	0.0	0.1
16	31.7	20.4	6.9	45.9	2.2	0.7	15.3	
22	16.7	20.6	17.1	23.0	18.0	9.5	18.2	
30	13.5	24.0	26.1	10.8	34.5	24.2	20.0	
44	10.4	14.6	19.2	6.1	23.5	29.7	16.7	
60	8.0	7.4	12.4	4.8	12.3	22.1	14.4	
72	2.4	1.8	3.7	1.1	2.0	3.8	3.0	
100	6.7	4.4	5.7	2.3	3.1	5.0	3.1	
150	4.5	2.2	3.5	2.0	2.0	2.8	4.6	
Pass 150	5.8	2.1	5.1	3.5	2.9	2.2	4.2	
Total	100.0	99.8	99.9	99.8	100.0	100.0	99.8	
Max. packing density, g./c.c. . . .	1.63	1.63	1.67	1.63	1.57	1.59	1.63	
Yield on washing, % . .	96	92	95	98	99	94	96	

(ii) *The Fine White Sandstone*.—The lenticular bed immediately overlying the coarse, white grit is composed of fine white sandstone. It differs principally from the grit in grain-size; muscovite flakes occur on some of the bedding planes. The microstructure of this grit is illustrated by Fig. 88.

Like the coarse white grit, this bed is built up of minor lenses the gradings of which differ appreciably. The extent of the variation is illustrated by the gradings of samples from localities *A* and *D* shown in Table XLIV.

TABLE XLIV.—*Mechanical Gradings of Samples of the Fine White Sandstone.*

Percentage Retained on B.S.I. Sieve No.—	Locality <i>A</i> .										Locality <i>D</i> .	
5	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.5	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.7	6.0	0.1	3.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
22	0.3	7.5	3.3	12.0	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.1
30	0.5	10.7	9.6	21.8	0.3	0.2	6.2	0.1	0.1	0.1	0.1	0.1
44	1.9	15.0	18.1	26.3	1.2	2.7	2.7	1.0	1.2	2.3	4.7	
60	22.9	23.8	28.1	20.1	14.9	14.7	9.0	12.1	25.0	8.3	14.7	
72	19.6	7.1	7.8	4.9	14.9	13.4	7.7	13.2	20.4	7.2	8.4	
100	38.2	14.8	16.6	6.3	43.0	38.9	34.7	51.3	33.2	38.2	32.5	
150	8.7	7.5	8.4	2.6	16.9	25.9	26.9	15.8	12.5	28.7	19.7	
Pass 150	7.1	6.2	7.8	3.0	8.7	3.9	12.9	6.5	7.8	15.1	19.8	
Total	99.9	100.0	99.8	100.2	99.9	99.8	100.2	100.0	99.8	100.0	100.0	
Max. packing density, g./c.c. . .	1.52	1.70	1.64	1.67	1.63	1.51	1.57	1.57	1.54	1.60	1.54	
Yield on washing, % . .	96	92	91	96	91	88	79	80	87	70	67	

(iii) *The Brown Grit*.—A thin bed of brown grit overlies the fine white sandstone. This brown grit resembles the normal Millstone Grit, for it has

a bond of limonite-stained sericite, and quartzitic aggregates are well developed. Near joints and major bedding planes, the grit has been bleached white to a depth of $\frac{1}{2}$ –1 in.

(iv) *The Compact Sandstone*.—The topmost lens is composed of very fine-grained compact sandstone, the colour of which ranges from brown to white. It differs from the other white grits (i) and (ii) in its compact texture; many of the grains are sutured together to form quartzitic aggregates. The grading of a typical sample is given in Table XLV.

TABLE XLV.—*Mechanical Grading of the Compact Sandstone.*

Percentage Retained on B.S.I. Sieve No.:	5.	8.	10.	16.	22.	30.	44.	60.	72.	100.	150.	Pass 150.	Total.
Locality E . . .	0.0	0.0	0.0	0.0	0.0	0.1	1.7	9.2	6.7	24.8	29.0	28.5	100.0

(b) *Physical Characteristics.*

The mechanical gradings of both the coarse grit (i) and the fine white sandstone (ii) vary more than those of most high-silica sands such as those of Leighton Buzzard and Chelford. The two beds are at present being developed for use as high-silica sands and, in order to obtain reasonably uniform products, the whole thickness of grit and of the sandstone will be crushed, washed, and screened.

Bulk samples of the two beds were examined in detail. Their physical characteristics are shown in Table XLVI. and Fig. 76. The characteristics

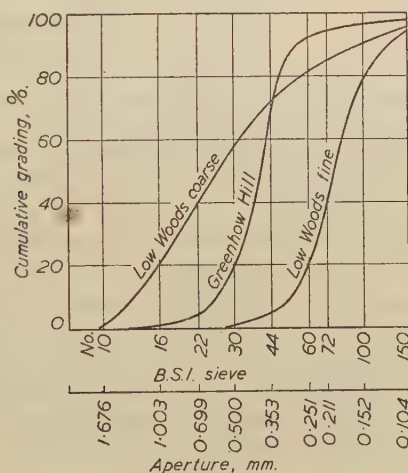


FIG. 76.—Mechanical Grading of Crushed Rocks from Low Woods Quarry and Greenhow Hill.

of Leighton Buzzard No. 52 sand and of Chelford sand are included in the table for comparison.

A.F.A. test-pieces, rammed 10 times, were prepared from the crushed rocks bonded with 5% of Fulbond No. 1. After firing at 1550° C. for 2 hr. the test-pieces were white and friable. The test-piece of the fine sandstone (ii) expanded 4.0%, while that of the coarse grit expanded 7.5%.

TABLE XLVI.—*The Physical Characteristics and Composition of Bulk Samples of the Coarse Grit (i) and Fine Sandstone (ii) of Low Woods Quarry.*

Percentage Retained on B.S.I. Sieve No.—	Coarse Grit (i).	Leighton Buzzard No. 52.	Fine Sandstone (ii).	ChelMord.
<i>Mechanical Gradings.</i>				
5	0.2	0.0	0.0	0.0
8	0.4	0.0	0.0	0.0
10	0.2	0.0	0.0	0.0
16	20.9	2.5	0.0	0.1
22	17.6	5.9	0.5	0.7
30	18.2	19.7	0.7	3.8
44	14.0	48.8	3.3	21.5
60	8.1	16.7	16.1	33.0
72	5.8	6.0	20.1	20.0
100	4.8	0.1	38.3	13.6
150	4.6	0.2	14.6	0.2
Pass 150	5.2	0.1	6.4	7.1
Total	100.0	100.0	100.0	100.0
Max. packing density, g./c.c. .	1.63	1.63	1.57	1.63
Specific surface, sq. cm./g. .	81.2	57.2	176.0	125.6
Average coefficient of angularity .	1.20	1.06	1.34	1.09
<i>Chemical Analyses.</i>				
SiO ₂ , %	98.87	98.75	99.03	97.13
TiO ₂ , %	0.01	0.02	0.01	0.02
Fe ₂ O ₃ , %	0.04-0.10	0.16	0.03-0.10	0.11
Al ₂ O ₃ , %	0.55	0.47	0.41	1.48
CaO, %	0.06	0.12	0.04	0.14
MgO, %	0.08	0.08	0.08	0.18
K ₂ O, %	0.12	0.14	0.12	0.38
Loss on ignition, %	0.20	0.20	0.20	0.50
Total	99.93	99.94	99.92	99.94

III.—THE QUARTZITIC GRIT OF GREENHILL HILL.

(a) *Geology.*

The quartzitic grit forms a low crag on exposed moorland over 900 ft. above sea-level, about $3\frac{1}{2}$ miles east of Grassington. The outcrop is partly obscured by loose blocks. The grit is false bedded, but unlike that of Low Woods Quarry it does not show marked variations in grading. The crag forms an arc some 200 yards long with a face 15-20 ft. high. Over the whole of this exposure, the grit appears to be even-grained, except for occasional thin bands of pebbles, especially in the top 2-3 ft. of grit near the middle of the crag.

Four shot-holes have been fired in the crag. Nos. 1 and 2, towards the central part of the crag, expose white, medium-grained grit, containing a small proportion of interstitial kaolinite and sericite; this grit is similar to the Coarse Grit of Low Woods Quarry, and, like it, breaks down into its constituent grains after a short period of milling. No. 3 shot-hole, at the western end of the crags, exposed a white sandstone with brown speckling due to limonite staining. No. 4 shot-hole, on the top of the crag near the middle, exposed pebbly white grit.

(b) *Physical Characteristics.*

The small variation in grading is illustrated by the gradings of crushed samples from shot-holes Nos. 1-3 given in Table XLVII.

TABLE XLVII.—*Mechanical Gradings of the Shot-hole Samples from Greenhow Hill.*

Percentage Retained on B.S.I. Sieve No.—	No. 1.	No. 2.	No. 3.
5	0.0	0.6	0.0
8	0.1	0.1	0.0
10	0.1	0.1	0.0
16	0.5	0.9	0.4
22	2.0	2.7	3.5
30	12.7	15.9	21.8
44	44.7	43.2	36.4
60	31.4	28.8	25.7
72	1.8	1.5	3.2
100	2.3	2.3	3.7
150	1.9	1.5	2.3
Pass 150	2.4	2.5	2.7
Total	99.9	100.1	99.7

The characteristics of an average sample from shot-holes Nos. 1-3 are given below and are illustrated by Fig. 76.

Yield on washing, %	97.1
Specific surface, sq. cm./g.	72.1
Average coefficient of angularity	1.17

A.F.A. test-pieces, rammed 10 times, were prepared from the crushed rock bonded with 5% of Fulbond No. 1. After firing at 1550° C. for 2 hr., the test-pieces were white and friable and had expanded 7.5%.

The chemical analyses of the unwashed sands from shot-holes Nos. 1 and 3, given below, show their particularly high silica content; the iron content of the white sandstone is low enough to make it suitable for glass manufacture.

	No. 1.	No. 3.
SiO ₂ , %	99.08	99.13
TiO ₂ , %	0.01	0.01
Fe ₂ O ₃ , %	0.04	0.17
Al ₂ O ₃ , %	0.43	0.26
CaO, %	0.02	0.01
MgO, %	0.04	0.02
K ₂ O, %	0.13	0.13
Loss on ignition, %	0.20	0.24
Total	99.95	99.97

IV.—CONCLUSIONS.

The quartzitic grits and sandstones described above indicate the possibilities of this hitherto unused source of high-silica sands. Some of the crushed rocks, especially when washed, are suitable for use as glass sands. Their gradings are comparable with those of high-silica sands used in steel foundries, but the grains are much more angular; this latter feature may cause difficulties in some types of foundry practice.

Part 8.—The Quartzitic Sandstones in the Cefn-y-Fedw Series of North Wales.

(Figs. 89 to 93 = Plates VII. and VIII.)

SYNOPSIS.

The quartzitic sandstones in the Cefn-y-Fedw Series of North Wales vary in texture from open to compact. Those with an open texture can be crushed easily and yield a well-graded high-silica sand. Those with a compact texture do not crush easily and yield mixtures of coarse, angular particles and very fine particles, that is, the characteristics desirable for silica-brick manufacture.

I.—INTRODUCTION.

THE Cefn-y-Fedw Series of North Wales is the approximate stratigraphical equivalent of the Millstone Grit Series of the Peak District, that is, it rests on limestone of Lower Carboniferous age and is succeeded by the Coal Measures. Sandstones form the greater part of the Series, and the harder beds give rise to escarpments the crests of which lie 1000–1600 ft. above sea-level. Glacial drift covers much of the outcrop, and solid rock is visible only near the crests of the escarpments or where stream courses have cut through the drift.

Some of the sandstones are of interest as sources of high-silica sand. The localities from which samples were obtained are given in Table XLVIII. and are indicated on the sketch-map, Fig. 77.

TABLE XLVIII.—*Index to Localities.*

Ref. No.	Locality.
C1	Quarry on north side of Mynydd Ddu, 4 miles south-south-west of Mold. Worked by Whiterock Products, Ltd., Pentrefelin Mills, Llangollen.
C2	Quarry at Crown Dale, 2 miles south-west of Caergwrle.
C3	Quarry at Bryn Yorkin, $\frac{1}{2}$ mile south-west of Caergwrle.
C4	Quarry at Bwlch Gwyn, 5 miles west-north-west of Wrexham.
C5	Quarry at Minera, 3 miles west of Wrexham.
C6	Quarry at Cefn-y-Fedw Farm, 2 miles north-east of Llangollen.

Only one of these localities adjoins a railway, the remainder are $\frac{1}{2}$ –3 miles from the nearest railway station.

II.—PETROLOGY.*

The sandstones of the Cefn-y-Fedw Series are generally false bedded. They are built up of thin lenticular beds stacked obliquely against each other. The lithology of each lens changes laterally and each may be different from its neighbours. Thus one lens may be composed of hard quartzitic sandstone, while an adjacent lens may be so friable that it crumbles between the fingers; such differences are conspicuous on Mynydd Ddu (C1). Pebble bands occur along some of the bedding planes, particularly at Bwlch Gwyn (C4) and Minera (C5).

At certain localities, notably at the latter two, the sandstones are bonded so completely with secondary silica that they are now quartzites.

The sandstones are composed of quartz in most instances accompanied by a small proportion of sericite and kaolinite. In section, most of the quartz grains contain linearly arranged inclusions, representing the traces

* Detailed descriptions of the rocks are given in Appendix I.

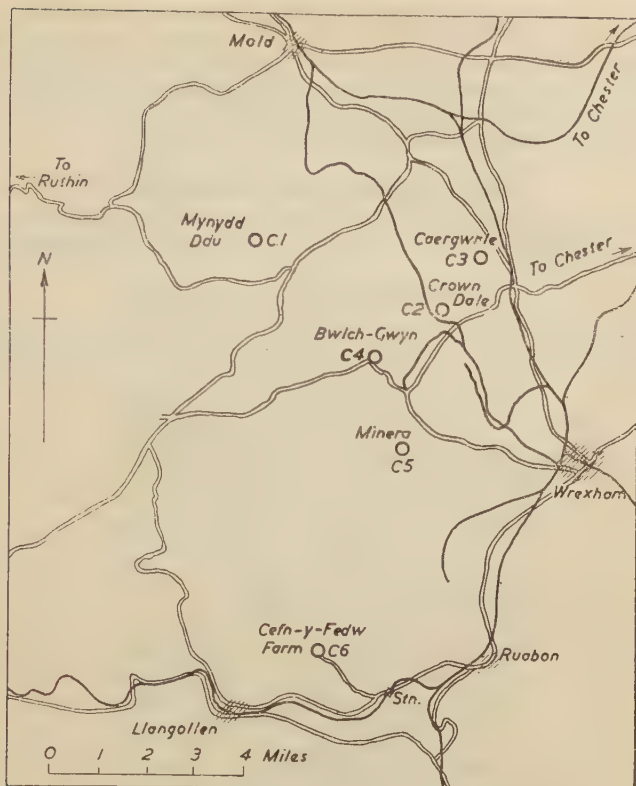


FIG. 77.—Quartzitic Sandstone Localities in North Wales.

of shear planes. Undulose extinction (strain shadows) is characteristic of most of the grains. Grains of quartzite are widely distributed. The grains are angular and their shape depends on the amount of corrosion and secondary silicification since the grains first accumulated. Such sericite and kaolinite as are present, form small pockets interstitial to the quartz grains.

The microstructure is of two types depending on the character of the secondary silicification. In the first type, illustrated by Fig. 91, the grains have been corroded at their points of contact until they are beginning to fit closely together to form quartzitic aggregates. This structure is characteristic of the samples from localities C1, C2, and C3. Quartzitic aggregates are better developed in the sample from locality C2 than in those from the other two localities. At all three localities, the rocks have an open texture and are friable.

In the second type of microstructure, the quartz removed by corrosion at the points of contact has been redeposited in the pores; consequently the rock has a compact texture and is best described as a quartzite. This pore-filling by secondary silica occurs in two ways. The secondary silica may be deposited as granules in the pores, in the manner illustrated by Fig. 92, or it may be attached to the quartz grains in optical continuity,

so that it now forms an integral part of the grain on which it is deposited, as shown in Fig. 93. In the latter case, the attached secondary silica can only be distinguished where traces of foreign matter or air bubbles are trapped along the junction. The rock from Bwlch Gwyn (C4) has the granular pore-filling, while the rocks from Minera (C5) and Cefn-y-Fedw Farm (C6) have the structure illustrated by Fig. 93.

III.—PHYSICAL CHARACTERISTICS.

The rocks were reduced to sand by crushing and milling. The characteristics of the sands so obtained depend on the texture of the rock.

(a) Rocks Having an Open Texture.

This group includes the rocks from localities C1-3. Their characteristics are shown in Table XLIX. and Fig. 78. Both the Mynydd Ddu

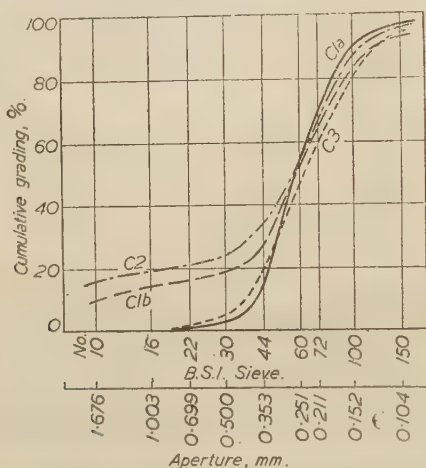


FIG. 78.—Mechanical Gradings of Friable Cefn-y-Fedw Sandstone.

and Caergwrle samples yield fairly well-graded, medium-grained sands composed of subangular grains; typical grains of the Caergwrle sand are shown in Fig. 89.

Cefn-y-Fedw sandstone, probably from the Mynydd Ddu quarry, is being crushed and washed by the White Sand and Silica Co., Ltd., Pentrefelin Mill, Llangollen. The characteristics of this washed sand are included in Table XLIX. It will be seen that it is rather finer than the samples collected from this locality and that the grains are rather more angular. This washed sand is intended for use as glass sand, as it has a low iron content.

The Crowndale rock contains more quartzitic aggregates than the Mynydd Ddu and Caergwrle rocks. These aggregates persist in the sand after milling and form large composite grains; nearly all the grains larger than 30 mesh are composite.

The Bwlch Gwyn Silica Co., Ltd., have produced a fine-grained sand from one of the less compact rocks in their quarries; the properties of this sand are included in Table XLIX.

TABLE XLIX.—*The Physical Characteristics of the Crushed Rocks.*

Rocks having an Open Texture.																Rocks having a Compact Texture.		
Percentage Retained on B.S.I. Sieve No.—	Mynydd Ddu.				Pentrefelin Mill (White Sand and Silica Co.) (Sand probably from Mynydd Ddu).		Crowndale, Locality C2.		Llangwyle, Locality C3.		Bwlch Gwyn (Commercial Sample).	Bwlch Gwyn Locality C4.	Minera, Locality C5.	Cefn-y-Fedw, Locality C6.				
	Locality C1a.		Locality C1b.		Washed.	Raw.	Washed.	Raw.	Washed.	Raw.								
	Raw.	Washed.	Raw.	Washed.														
5	0.3	0.2	2.0	1.5	0.0	0.0	8.5	7.6	0.0	0.0	0.0	12.2	35.4	10.5				
8	0.2	0.2	3.9	3.4	0.0	0.0	3.8	3.0	0.2	0.2	0.0	21.6	19.3	12.8				
10	0.0	0.1	2.7	2.5	0.0	0.0	4.0	4.2	0.1	0.2	0.0	4.5	4.2	2.9				
16	0.3	0.3	5.4	5.3	0.6	0.6	2.6	2.9	0.5	0.4	0.0	10.6	8.2	6.6				
22	0.3	0.2	1.8	2.1	1.1	1.1	1.6	1.9	0.6	0.5	0.5	4.5	2.4	2.3				
30	1.7	1.8	2.6	3.2	2.8	2.8	3.1	3.7	3.2	3.6	0.6	4.3	1.9	2.5				
44	9.5	11.0	6.0	6.6	8.6	8.6	10.8	11.2	12.6	13.8	1.7	4.9	2.4	4.1				
60	41.9	42.1	29.3	32.2	19.9	19.9	15.3	17.3	29.6	31.2	15.7	10.0	4.4	10.6				
72	13.7	14.1	9.9	10.8	18.8	18.8	19.1	21.5	10.0	10.1	24.2	2.9	2.9	6.1				
100	22.0	23.0	19.6	22.1	32.7	32.7	18.1	19.2	22.8	25.6	48.9	7.4	6.5	17.6				
150	6.6	7.0	8.7	10.3	13.1	13.1	7.5	7.5	14.2	14.4	5.0	6.7	5.9	13.7				
Pass 150	3.5	...	8.1	...	2.4	2.4	5.6	...	6.2	...	3.4	10.6	6.5	10.3				
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0			
Yield on washing, %	95.7	...	91.0	93.5	...	93.2			
Max. packing density, g./c.c.	1.57	...	1.69	...	1.63	1.63	1.60	...	1.66			
Specific surface, sq. in./g.	115.9	...	112.6	...	133.2	133.2	115.6	...	112.8			
Average coefficient of angularity	1.11	...	1.09	...	1.15	1.15	1.12	...	1.10			

The chemical analyses of the two rocks having an open texture are as follows :

	Pentrefelin Mill (probably from Mynydd Ddu).	Bwlch Gwyn (Commercial Sample).
SiO ₂ , %	99.17	98.86
TiO ₂ , %	0.08	0.07
Fe ₂ O ₃ , %	0.038	0.14
Al ₂ O ₃ , %	0.29	0.19
CaO, %	0.06	0.04
MgO, %	0.09	0.10
K ₂ O, %	0.10	0.24
Loss on ignition, %	0.15	0.30
Total	99.978	99.94

(b) *Rocks Having a Compact Texture.*

This group includes the rocks from localities C4-6. Their characteristics are shown in Table XLIX. and Fig. 79. The grading of the samples after crushing is characterized by coarse angular fragments larger than 10

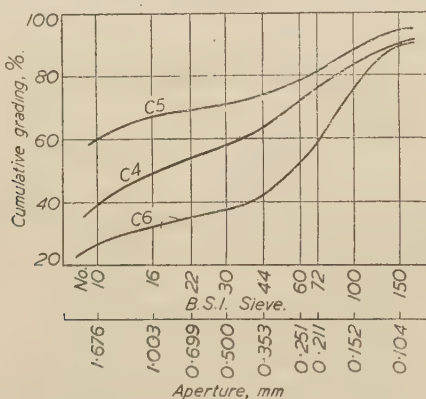


FIG. 79.—Mechanical Gradings of Compact Cefn-y-Fedw Sandstone.

mesh and by a noteworthy amount of fines. The relative proportions of coarse and fine grains depends on the period of milling and the severity of the milling conditions. This type of grading results because the rock behaves as if it is homogeneous rather than as an aggregate of grains, consequently crushing produces fractures which are not related to the shape of the constituent grains. The double-graded character of the crushed compact Bwlch Gwyn rock is illustrated by Fig. 90. The Minera and Cefn-y-Fedw Farm rocks yield similar double-graded sands.

All the sands are very refractory. When bonded with 5% of Fulbond No. 1, A.F.A. test-pieces, rammed 10 times, showed an expansion of 7.5% after firing at 1550° C. for 2 hr. The test-pieces were white and friable, that is, the grains had only just begun to sinter together.

IV.—CONCLUSIONS.

Certain of the quartzitic sandstones of the Cefn-y-Fedw Series when crushed and milled yield well-graded high-silica sands, composed of angular

quartz grains. The most suitable sandstones are even-grained and friable; their texture is open and they are composed almost wholly of quartz. As their texture becomes more compact, the crushed rock becomes less well-graded and the proportion of very coarse and fine particles increases until a grading is obtained more suited for silica-brick manufacture than for high-silica sands for foundry use. The high proportion of strained grains will produce a rather high proportion of fines in a sand system.

APPENDIX I.—*Detailed Description of the Rocks.*

C1, Mynydd Ddu.

Transport Facilities.—4 miles by road from Coed Talon Station.

Petrology.—Samples were obtained from two faces working different lenses in the sandstone. The first sample (C1a) was obtained from the face worked for glass sand, while the second sample was obtained from a face working a pale-brown sandstone. The glass-sand bed is a white, porous, rather friable sandstone containing a very small proportion of interstitial clay. The brown bed is similar, but the quartz grains are slightly stained with limonite.

Both rocks are composed of angular quartz grains together with a very small amount of sericite. The majority of the quartz grains contain linearly-arranged inclusions and many have strain shadows. Grains of quartzite are fairly common. Corrosion has pitted the grains, giving them a rather frilled outline in section. A few of the grains are coated with secondary silica. Quartzitic aggregates are poorly developed.

C2, Crowndale.

Transport Facilities.—Adjoins railway.

Petrology.—A white, fairly friable, porous sandstone containing a small proportion of interstitial clay; near joints and major bedding planes it is slightly stained with limonite.

The rock is similar to that of Mynydd Ddu, but contains both sericite and kaolinite, and quartzitic aggregates are developed more extensively.

C3, Caergwle.

Transport Facilities.— $\frac{1}{2}$ mile by road from Caergwle Station.

Petrology.—Similar to the glass-sand bed of Mynydd Ddu, but contains even less interstitial clay.

C4, Bwlch Gwyn.

Petrology.—A white, very compact, rather glassy rock, better described as a quartzite than as a sandstone. It is composed of quartz grains cemented by granular silica. Most of the quartz grains exhibit strain shadows and contain linearly arranged inclusions. Quartzite grains are abundant. Close to the quartz grains, the silica cement appears to be fibrous rather than granular; the fibres radiate from the quartz grains and their pattern is suggestive of chalcedony. A few wisps of sericite occur in the rock.

C5, Minera.

Transport Facilities.— $\frac{1}{2}$ mile by road from Berwig Station.

Petrology.—A white, compact sandstone or quartzite slightly stained with limonite near the joints. It is composed of angular quartz grains, most of which contain linearly arranged inclusions and exhibit strain shadows. Grains of quartzite are common. The quartz is accompanied by a trace of kaolinite and sericite. Corrosion and the deposition of secondary silica on the quartz grains have together produced the quartzitic microstructure.

C6, Cefn-y-Fedw Farm.

Transport Facilities.—2 miles by road from Trevor Station.

Petrology.—A white, compact sandstone slightly speckled with limonite. It is similar to the Minera rock, but contains more sericite, and secondary silicification is more conspicuous.

APPENDIX II.—The Characteristics of Two Soft Sandstones from a Quarry at Caergwrle, Nr. Wrexham.*

White Sample.—A medium- to fine-grained, white, fairly compact sandstone.

Pink Sample.—A little less compact than the white sample. It is slightly stained with iron oxide and contains fairly numerous small dark aggregates, up to 4 mm. in size, which also contain iron oxide. Both samples crush fairly readily to their constituent quartz grains. Portions of the sand obtained by crushing and light milling were washed, and the properties of the unwashed and washed sands are given in Table L.

TABLE L.—Physical Characteristics of Two Caergwrle Sandstones.

Percentage Retained on B.S.I. Sieve No.—	White Sample.		Pink Sample.	
	Unwashed.	Washed.	Unwashed.	Washed.
10	0.0	0.0	0.0	0.0
16	0.4	0.4	0.2	0.2
22	2.0	2.4	1.3	1.4
30	11.9	13.1	6.0	6.8
44	20.9	21.8	21.5	23.6
60	18.0	21.0	22.7	26.1
72	10.1	10.9	11.3	12.7
100	12.6	14.6	13.5	14.5
150	14.7	15.8	13.5	14.7
Pass 150	9.4	0.0	10.0	0.0
Total	100.0	100.0	100.0	100.0
Yield on washing, % . . . . .	...	90.1	...	89.0
Specific surface, sq. cm./g. . . . .	...	130.3	...	142.3
Average coefficient of angularity . . . . .	...	1.14	...	1.16

The chemical analyses of the two sandstones are as follows :

	White Sample.		Pink Sample.	
	Unwashed.	Washed.	Unwashed.	Washed.
SiO ₂ , %	99.03	99.11	98.05	98.67
TiO ₂ , %	0.01	0.01	0.02	0.02
Fe ₂ O ₃ , %	0.11	0.08	0.56	0.34
Al ₂ O ₃ , %	0.30	0.26	0.70	0.41
CaO, %	0.05	0.05	0.05	0.05
MgO, %	0.07	0.07	0.08	0.08
K ₂ O, %	0.10	0.10	0.10	0.10
Loss on ignition, %	0.30	0.26	0.36	0.28
Total	99.97	99.94	99.94	99.95

* Submitted by Messrs. N. Clarke and Co., Sheffield.

Part 9.—The Rotten-Rock Moulding Sands of Durham and South Northumberland.

(Figs. 97 to 105 = Plates IX. and X.)

SYNOPSIS.

The tentative conclusions drawn in the preliminary account given in Part 4 of this paper are confirmed and extended.

The detailed properties of the rotten rocks from seventeen localities are recorded. Comparisons drawn from these data and from foundry trials show that a bond composed of moderately or strongly pleochroic hydrobiotite is preferable to one composed of slightly pleochroic hydrobiotite or of sericite.

I.—INTRODUCTION.

THE rotten-rock moulding sands of Durham and south Northumberland are prepared from certain friable grits in the Millstone Grit Series. These grits can be reduced by crushing and milling to form naturally-bonded moulding sands. At the present time, a considerable tonnage is being won from quarries situated on the fells between the Wear and the Tyne for use in the steel foundries of Tees-side, Tyneside, and elsewhere.



FIG. 80.—Localities Examined in Durham and South Northumberland. Outcrop of Millstone Grit stippled.

A preliminary account of the properties of some of these rotten-rock moulding sands was given in Part 4 of this paper. Further samples of the rotten rocks have been collected by Mr. W. Anderson and Mr. R. G. Carruthers of the Geological Survey, Newcastle-on-Tyne. The extended data now available from these new samples form the basis of the present section; it confirms and extends the tentative conclusions, drawn in the earlier account, relating the mineralogical constitution and microstructure of the rotten rocks to their moulding characteristics.

Apart from that account, there is little published information on the rotten-rock moulding sands. The properties of "Northern Sand" from Tow Law, County Durham, were examined in the First Report of the Moulding Materials Sub-Committee.* Certain of the moulding characteristics of the rotten rocks, described in this paper, were included in a publication by R. G. Carruthers and W. Anderson.†

The localities from which the samples were obtained are given in Table I.I. The localities are indicated on the sketch-map, Fig. 80. It will be seen that the quarries either adjoin railway sidings, or that they are only a few miles by road from the nearest station.

TABLE I.I.—*Index to Localities.*

Ref. No.	Source.	Location.
W1	Parkhead Quarry.	Adjoining Stanhope-Edmondbyers road, 2½ miles north of Stanhope.
W2	Disused Quarry, near Waskerley.	Adjoining L.N.E. mineral railway, 1½ miles west of Waskerley.
W3	Disused Quarry, near Waskerley.	150 yd. north-west of Locality W2.
W4	Dead Friars' Quarry.	Adjoining the Stanhope-Blanchland road, 4 miles north-north-west of Stanhope.
W5	Weather Hill Quarry.	Adjoining Stanhope-Edmondbyers road, 1½ miles north of Stanhope.
W6	Harperley Hill Quarry.	Adjoining road midway between Stanhope and Crook.
W7	Viewly Hill Quarry.	Adjoining Wolsingham-Consett road, 2½ miles from Wolsingham.
W8	Feldon Carrs.	On the east side of Stanhope-Edmondbyers road, 5½ miles from Stanhope.
W9	Hisehope Reservoir.	Adjoining moorland road to Hisehope Reservoir, 500 yd. to the north of Stanhope-Edmondbyers road and 1½ miles west of Waskerley.
W10	Millstone Rigg.	500 yd. east-south-east from Weather Hill Engine on the Stanhope-Edmondbyers road, 2 miles from Stanhope.
W11	Bridge Old Quarry.	2 miles west of Stanhope.
W12	Sand Edge.	Diggings ¾ mile north of Redmires Farm, 3½ miles north of Wolsingham.
W13	Redmires.	Quarry 400 yd. north of Redmires Farm, 3 miles north of Wolsingham.
W14	Baal Hill.	Quarries 1½ miles north of Wolsingham, on the west side of the moorland road running north from Wolsingham Farm.
W15	Cleugh.	Quarry 1 mile south-east of Tow Law.
W16	Apperley.	Natural exposure ½ mile south-south-west of Apperley Farm, 2½ miles south of Stocksfield.

II.—STRATIGRAPHY.

In Northumberland and Durham, the Millstone Grit is frequently defined as comprising the measures lying between the lowest coal of the Coal Measures and the highest limestone. Three grits are known in Durham, parted by considerable masses of shales and clays with occasional thin coals, the whole amounting to a thickness of 300 ft. In Northumberland the supposedly equivalent measures are 600 ft. thick and include less shale.‡

Mr. W. Anderson, who collected samples W8-W15, reported that of

* *The Iron and Steel Institute*, 1938, *Special Report No. 23*, p. 197.

† "Some Refractory Materials in North-Eastern England." Geological Survey Wartime Pamphlet No. 31, 1943.

‡ Geological Survey, "British Regional Geology : Northern England."

the three grits in Durham, the top grit is always a massive freestone, rather fine-grained, while the bottom grit is hard and massive; the middle grit is the only one of the three to be completely rotted. With the exception of Weather Hill Quarry (W5), all the quarries recorded in Table LI. appear to be in the middle grit; Weather Hill Quarry is in the bottom grit.*

III.—PETROLOGY.*

The typical rotten rocks of this district are composed mainly of quartz, secondary mica, and in some examples, kaolinite. Felspar has not been detected in any of the samples from the middle grit, but the Weather Hill sample (W5) from the bottom grit contains 2-3% of felspar. The rocks are friable and, in some instances, can be crushed readily between finger and thumb. As detailed descriptions of the samples are given in the Appendix, only their general features will be described below.

Mineral Constituents.

Quartz.—This is the principal constituent of the rocks. Some of the quartz grains are free from strain shadows and contain only a few scattered inclusions, while others exhibit well-marked strain shadows and contain numerous shear planes which appear in the microsection as linearly-arranged inclusions. The latter type of grain is less resistant to fracture during milling than the former and by fracturing tends to yield an undesirably high proportion of grain of silt-grade dimensions. Furthermore, such strained grains fracture more readily when subject to thermal shock such as occurs during casting. The relative proportions of the two types vary from locality to locality. If a sand containing a high proportion of strained grains is employed in a foundry sand system, the proportion of silt in the system will tend to increase more rapidly than if a sand containing few strained grains is used. Quartzite grains are conspicuous in samples containing a high proportion of strained grains. An example of a grain exhibiting strain shadows and linearly-arranged inclusions is shown in Fig. 97; a quartzite grain is included in the field.

The shape of the quartz grains varies from subangular to angular. Many of the grains have been corroded since deposition and now have frilled outlines. An extreme example of the "frilling" of a quartz grain is shown in Fig. 98.

Kaolinite.—This mineral is a fairly common constituent of the rotten rocks. It occurs as aggregates which may show vermicular stacking of the constituent flakes. A typical aggregate is shown in Fig. 99.

Secondary Mica.—More than 25% of the typical rotten rock is composed of clay minerals of this group. When the rock is crushed and milled for use as a moulding sand, these clay minerals, together with any kaolinite that may be present, form the bond between the sand grains. Two types of secondary mica can be distinguished. The first or sericite type is derived principally from felspar; it contains little or no magnesium or iron. The second or hydrobiotite type is derived mainly from biotite, augite, hornblende, and other ferromagnesian minerals; it contains a noteworthy proportion of iron and magnesium. The atomic structures of sericite and hydrobiotite are similar to those of the primary micas, muscovite and biotite, respectively; they differ from the primary micas in containing more hydroxyl ions and fewer potassium ions.

Various definitions of sericite and hydrobiotite have been given by different authors. Hydrobiotite is used here to refer to those secondary micas which, under the microscope, exhibit pleochroism in shades of greenish-brown or brown; the intensity of the pleochroism varies with the iron

* Detailed descriptions of the rocks are given in the Appendix.

content. Sericite, on the other hand, does not exhibit pleochroism, although, when examined under high power, change of relief may sometimes be detected; it sometimes has a faint brown colour due to limonite staining.

Though some of the rotten rocks contain a few large flakes of hydrobiotite (see Fig. 100), apparently derived from the alteration of biotite, nearly all the secondary mica occurs as aggregates of flakelets less than 5μ across. The pleochroism of each aggregate may vary considerably. Several aggregates are shown in Fig. 101; the central part of one aggregate is almost colourless and is composed of sericite, while the periphery is dark, indicating the brown pleochroism of hydrobiotite. The adjacent larger aggregate has a core of kaolinite surrounded by secondary mica which varies from sericite at one end of the aggregate to hydrobiotite at the other end; under crossed nicols (Fig. 102), the kaolinite core is readily distinguished from the micaceous border, as it appears dark while the border appears light owing to the difference in birefringence.

The X-ray diffraction patterns shown in Fig. 105 were obtained from the finer fractions of the clay washed from several of the rotten rocks. In each of these rocks, the degree of pleochroism observed in the secondary mica was nearly uniform. Fig. 105(a) shows the pattern of the most strongly pleochroic secondary mica, a hydrobiotite containing a considerable amount of iron. Figs. 105(b) and (c) show the patterns of moderately and slightly pleochroic hydrobiotite respectively, while Fig. 105(d) shows the pattern of the non-pleochroic mica, sericite. All four patterns indicate the presence of quartz and mica. Unfortunately it was not possible to concentrate the mica sufficiently by settling for its weaker lines to appear in the pattern; this difficulty is enhanced by the occurrence of quartz inclusions in the mica flakes. However, the patterns indicate the close structural similarity between the four secondary micas.

The microscopic and X-ray diffraction data suggest that, in the process of weathering, hydrobiotite may be altered to sericite and then sericite may be replaced by kaolinite. The first change is marked by a progressive decrease in the intensity of the pleochroism, while the second is indicated by a sharp change in the birefringence.

Since the middle grit is the only one of the three grits to be completely rotted, that is, to contain no feldspar, Mr. W. Anderson considers that this grit may have been deposited in the weathered or rotted state; however, it is possible that the rotting took place shortly after the deposition of the grit and before the deposition of higher beds. A seggar and ganister resting on the rotted grit may have been leached at the same time.

Feldspar.—Microcline, showing slight alteration, is the only type of feldspar detected in the Weather Hill sample (W5). Though the sericite is, no doubt, derived in part from feldspar and not from the breakdown of hydrobiotite, yet there are no pseudomorphs after feldspar in the samples from the middle grit.

Microstructure.

The proportion of bond in the rotten rocks was determined by micro-metric analysis. The results are summarized in Table LII.

It will be seen that the proportion of bond varies from 25 to 33%. The differences between the microstructures of the rotten rocks are concerned mainly with the relative distribution of quartz and bond. Two types of microstructure can be distinguished. In the first type, each quartz grain is separated from the adjacent grains by a film of the bonding minerals; this microstructure is illustrated by Fig. 103. In the second type, groups of quartz grains are sutured together to form quartzitic aggregates, and the bonding minerals are interstitial to these aggregates; this microstructure is illustrated by Fig. 104.

TABLE LII.—*Micrometric Analyses of the Rotten Rocks.*

Ref. No.	Source.	Quartz, %.	Bond: Secondary Mica and Kaolinite, %.
W1	Parkhead Quarry.	73.4	26.6
W2	Disused Quarry, near Waskerley.	70.0	30.0
W3		74.7	25.3
W4M	Dead "Friars" Quarry" (Main "Face).	69.7	30.3
W4R	" " " (Right Face).	72.5	27.5
W5	Weather Hill Quarry.	71.0	29.0
W6	Harperly Hill Quarry.	73.5	26.5
W7	Viewly Hill Quarry.	66.7	33.3
W8	Feldon Carrs.	67.0	33.0
W9	Hisehope Reservoir	71.0	29.0
W10	Millstone Rigg.	69.5	30.5
W11	Bridge Old Quarry.	74.2	25.8
W12	Sand Edge.	74.8	25.2
W13	Redmires.	69.5	30.5
W14	Baal Hill.	67.0	33.0
W15	Cleugh.	68.8	31.2
W16	Apperley.	68.0	32.0

In some rotten rocks the first type is predominant, while in others the second type is well developed. The presence of quartzitic aggregates, especially those with intricately sutured grain junctions, is a disadvantage, for such aggregates are not easily reduced to their constituent grains by milling and may persist in the milled sand and so cause flaws in the mould surface.

IV.—MOULDING CHARACTERISTICS.

The samples were prepared for the moulding tests by passing through a small jaw crusher which reduced the rock to fragments less than $\frac{1}{4}$ in. across; the crushed rock was then milled so as to separate the quartz grains as thoroughly as possible.

In order to relate the moulding characteristics to the mineralogical constitution of the bond, it is convenient to group the data so that this relationship can be considered independently of other factors such as mechanical grading. Accordingly the samples are divided into three groups; in each group, the samples have similar mechanical gradings and similar permeability numbers. A further subdivision may be made according to the predominant constituent of the bond. The resulting classification is given in Table LIII.

TABLE LIII.—*The Classification of the Rotten Rocks.*

Constitution of Bond.	Group A.	Group B.	Group C.
Strongly pleochroic hydrobiotite	W7	...	...
Moderately pleochroic hydrobiotite	W2	...	W4M
Slightly pleochroic hydrobiotite	W10	W3 W4R W6 W11	W5 W12
Sericite—little or no pleochroism.	W15	W8 W13	W1 W9
Sericite with much kaolinite.	W16	...	W14

In order to relate the moulding characteristics to the mineral constitution of the bond, it might seem more satisfactory at first sight to wash the bond out of the milled samples and then to employ these washings to bond a high-silica sand. Thus the moulding characteristics could be discussed in relation to the mineralogical constitution of the bond quite

TABLE LIV.—*The Mechanical Gradings of the Rotten Rocks in Group A.*

Percentage Retained on B.S.I. Sieve No.—	W7.	W2.	W10.	W15.	W16.
5	0.0	0.0	0.0	0.0	0.0
8	0.2	0.1	0.0	0.2	0.1
10	0.4	0.4	0.3	0.3	0.2
16	17.2	20.1	14.7	8.5	18.4
22	9.6	11.5	13.7	11.9	20.9
30	12.0	11.6	14.7	17.4	23.9
44	16.8	14.6	14.4	22.1	16.7
60	19.8	17.6	18.0	17.0	8.3
72	4.4	4.4	6.8	3.9	1.6
100	7.9	9.6	9.4	7.0	3.0
150	4.6	4.5	4.0	5.0	2.2
Pass 150	6.9	5.6	3.9	6.6	4.7
Total	99.8	100.0	99.9	99.9	100.0

TABLE LV.—*The Moulding Characteristics of the Rotten Rocks in Group A.*

Test-pieces of A.F.A. dimensions; rammed 10 times.

Moisture Content, %.	6.0.	7.0.	8.0.	9.0.	10.0.
<i>W7, Viewly Hill.</i>					
Bulk density, g./c.c. . .	1.75	1.77	1.79	1.81	1.83
Permeability No. . . .	15.0	15.0	14.0	13.0	12.0
Green strength, lb./sq. in. .	34.5	32.0	30.2	28.7	27.5
Dry strength, lb./sq. in. .	405	470	530	595	640
<i>W2, Waskerley.</i>					
Bulk density, g./c.c. . .	1.75	1.77	1.79	1.81	1.83
Permeability No. . . .	15.0	13.0	12.0	11.0	10.0
Green strength, lb./sq. in. .	21.8	21.5	20.5	19.2	18.3
Dry strength, lb./sq. in. .	120	160	205	255	305
<i>W10, Millstone Rigg.</i>					
Bulk density, g./c.c. . .	1.78	1.80	1.83	1.85	1.87
Permeability No. . . .	23.0	20.0	18.0	16.0	15.0
Green strength, lb./sq. in. .	33.0	27.5	24.0	18.0	16.0
Dry strength, lb./sq. in. .	140	175	210	250	290
<i>W15, Cleugh.</i>					
Bulk density, g./c.c. . .	1.80	1.83	1.85	1.87	1.89
Permeability No. . . .	24.0	21.0	19.0	18.0	17.0
Green strength, lb./sq. in. .	25.5	21.0	18.0	14.0	11.0
Dry strength, lb./sq. in. .	130	160	205	250	290
<i>W16, Apperley.</i>					
Bulk density, g./c.c. . .	1.73	1.75	1.77	1.79	1.81
Permeability No. . . .	30.0	28.0	27.0	27.0	26.0
Green strength, lb./sq. in. .	18.0	14.2	11.4	10.2	6.5
Dry strength, lb./sq. in. .	100	127	145	165	190

TABLE LVI.—*The Refractoriness of the Rotten Rocks in Group A.*

A.F.A. test-pieces, rammed 10 times, fired at 1550° C. for 2 hr.

Source.	Appearance of Test-Piece.	Shrinkage, %.
W7, Viewly Hill.	Grey-brown with slightly glazed surface.	7.5
W2, Wakerley.	Grey with slightly glazed surface.	7.5
W10, Millstone Rigg.	Grey with slight mottling; surface glazed.	10
W15, Cleugh	White; grains very well fritted together.	2.5
W16, Apperley.	Grey; grains well fritted together.	Nil

independently of other factors. However, this procedure does not take into account the important distinction between "static" and "mobile" bond, a distinction first drawn by G. W. H. Holmes.* He stated that "the static bond, although small in amount, certainly has a greater tendency to strengthen the sand than would a similar amount of mobile bonding material coupled with smooth grains of silica."

Group A.—The crushed rocks in this group have permeability numbers of 10 to 30 and, with the exception of W16, 75–80% of their grains are retained by B.S.I. sieve No. 60; W6 is slightly coarser than the other rocks in this group, as will be seen from Table LIV. Their moulding characteristics and behaviour when fired are recorded in Tables LV. and LVI. respectively.

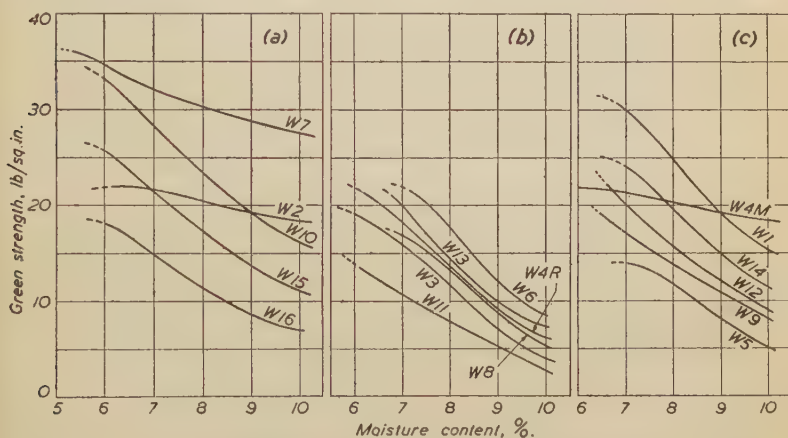


FIG. 81.—Green Strength of Rotten-Rock Moulding Sands of Groups A, B, and C.
A.F.A. test-pieces, rammed 10 times.

The green-strength/moisture curves for this group, shown in Fig. 81(a), demonstrate the marked differences in the bonding properties of the secondary micas. The curves for W2 and W7, in which the micas are moderately and strongly pleochroic respectively, have gentle gradients, while those for W10, W15, and W16, in which the micas are less pleochroic, have steep gradients. The dry-strength/moisture curves for W2 and W7, shown in Fig. 82(a), have rather steeper gradients than those for the other rocks in this group.

Group B.—The crushed rocks in this group have permeability numbers

* *Journal of The Iron and Steel Institute*, 1922, No. II., p. 61.

of 30 to 70, though some of the values for *W4R* and *W11* are just outside these limits. The mechanical gradings given in Table LVII. show that, with the exception of *W11*, 82-87% of their grains are retained by B.S.I. sieve No. 60; *W6* is slightly coarser than the other rocks. Their bonding minerals are slightly pleochroic or non-pleochroic. Moulding characteristics and behaviour on firing are recorded in Tables LVIII. and LIX.

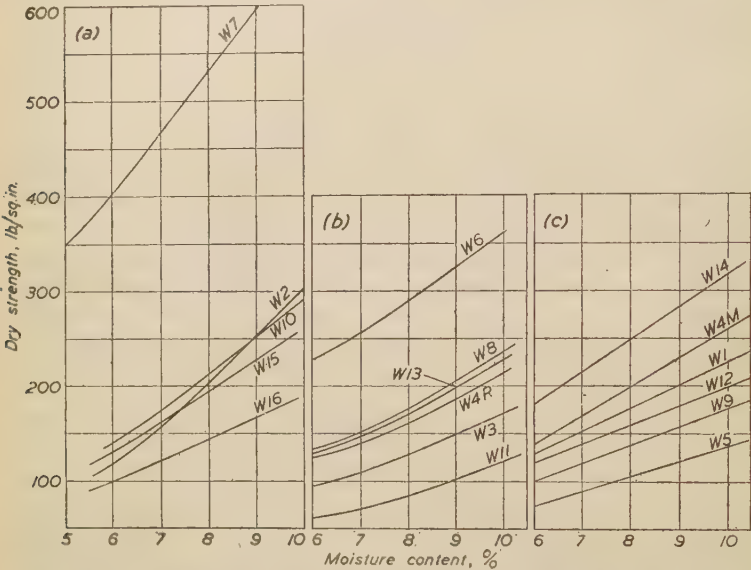


FIG. 82.—Dry Strength of Rotten-Rock Moulding Sands of Groups A, B, and C. A.F.A. test-pieces, rammed 10 times, dried at 200° C.

TABLE LVII.—*The Mechanical Gradings of the Rotten Rocks in Group B.*

Percentage Retained on B.S.I. Sieve No.—	W3.	W4R.	W6.	W11.	W8.	W13.
5 . . .	0.0	0.0	0.0	0.0	0.0	0.0
8 . . .	0.4	0.1	0.5	0.6	0.7	0.3
10 . . .	0.6	0.2	2.6	5.1	0.4	0.3
16 . . .	18.4	21.7	17.4	20.9	11.0	12.7
22 . . .	14.2	15.9	25.8	23.2	10.4	17.1
30 . . .	16.7	17.4	13.2	22.8	13.0	22.9
44 . . .	20.9	16.4	14.8	13.3	24.4	17.1
60 . . .	13.4	14.3	10.9	7.6	25.9	12.4
72 . . .	2.3	2.8	2.0	1.0	4.6	3.0
100 . . .	4.5	4.4	4.4	3.0	5.1	5.9
150 . . .	3.3	2.6	3.4	1.3	2.1	3.6
Pass 150 . . .	5.2	4.1	4.9	1.3	2.3	4.6
Total . . .	99.9	99.9	99.9	100.1	99.9	99.9

The green-strength/moisture curves for this group, shown in Fig. 81(b), have steep gradients comparable with those of *W10*, *W15*, and *W16* in Group A. The dry-strength/moisture curves, shown in Fig. 82(b), have similar gradients.

TABLE LVIII.—*The Moulding Characteristics of the Rotten Rocks in Group B.*

Test-pieces of A.F.A. dimensions; rammed 10 times.

Moisture Content, %.	6-0.	7-0.	8-0.	9-0.	10-0.
<i>W3, Waskerley.</i>					
Bulk density, g./c.c.	1.71	1.73	1.76	1.78	1.80
Permeability No.	53.0	60.0	60.0	58.0	56.0
Green strength, lb./sq. in. . . .	19.0	15.5	11.0	7.0	4.0
Dry strength, lb./sq. in.	95.0	110.0	130.0	150.0	170.0
<i>W4R, Dead Friars' Quarry (Right Face).</i>					
Bulk density, g./c.c.	1.73	1.74	1.76	1.78	1.80
Permeability No.	40.0	35.0	30.0	28.0	25.0
Green strength, lb./sq. in. . . .	21.5	18.0	13.5	9.0	6.0
Dry strength, lb./sq. in.	125.0	140.0	160.0	185.0	215.0
<i>W6, Harperley Hill.</i>					
Bulk density, g./c.c.	1.71	1.73	1.75	1.77	1.79
Permeability No.	55.0	53.0	50.0	48.0	45.0
Green strength, lb./sq. in. . . .	21.2	21.5	18.2	12.0	8.5
Dry strength, lb./sq. in.	225.0	255.0	290.0	325.0	360.0
<i>W11, Bridge Old Quarry.</i>					
Bulk density, g./c.c.	1.77	1.78	1.78	1.80	1.82
Permeability No.	88.0	80.0	75.0	70.0	65.0
Green strength, lb./sq. in. . . .	13.5	10.5	8.0	5.0	2.5
Dry strength, lb./sq. in.	60.0	70.0	80.0	105.0	125.0
<i>W8, Feldon Carrs.</i>					
Bulk density, g./c.c.	1.79	1.80	1.81	1.82	1.83
Permeability No.	43.0	41.0	39.0	38.0	36.0
Green strength, lb./sq. in. . . .	16.9	16.5	13.3	8.5	5.0
Dry strength, lb./sq. in.	125.0	155.0	171.0	205.0	240.0
<i>W13, Redmires.</i>					
Bulk density, g./c.c.	1.80	1.82	1.84	1.86	1.88
Permeability No.	55.0	51.0	48.0	45.0	42.0
Green strength, lb./sq. in. . . .	19.4	20.0	14.5	10.0	7.0
Dry strength, lb./sq. in.	130.0	145.0	165.0	200.0	225.0

TABLE LIX.—*The Refractoriness of the Rotten Rocks in Group B.*

A.F.A. test-pieces, rammed 10 times, fired at 1550° C. for 2 hr.

Source.	Appearance of Test-Piece.	Shrinkage, %.
<i>W3, Waskerley.</i>	White; grains well fritted together.	Nil
<i>W4R, Dead Friars' Quarry (Right Face).</i>	White, slightly mottled; grains well fritted together.	Nil
<i>W6, Harperley Hill.</i>	Pale brown, slightly mottled; grains well fritted together.	Nil
<i>W11, Bridge Old Quarry.</i>	Grey; grains well fritted together.	—1.0
<i>W8, Feldon Carrs.</i>	Grey; grains well fritted together.	3.0
<i>W13, Redmires.</i>	Grey with brown mottling; slightly glazed surface.	10

Group C.—With the exception of *W14*, the crushed rocks in this group have permeability numbers of 20 to 40; *W14* has a lower permeability. The rocks are not so coarse-grained as those in the other groups. Their

TABLE LX.—*The Mechanical Gradings of the Rotten Rocks in Group C.*

Percentage Retained on B.S.I. Sieve No.—	W4M.	W5.	W12.	W1.	W9.	W14.
5 . . .	0.0	0.0	0.1	0.2	0.2	0.0
8 . . .	0.2	0.1	0.2	2.4	0.1	0.1
10 . . .	0.6	0.1	0.1	1.3	0.0	0.2
16 . . .	6.6	4.4	8.8	8.7	6.4	8.0
22 . . .	7.4	7.0	11.2	9.9	8.0	7.9
30 . . .	14.4	11.4	15.0	14.7	10.5	9.3
44 . . .	21.9	18.4	15.6	19.7	19.7	16.0
60 . . .	21.3	24.6	18.9	28.9	24.6	27.0
72 . . .	4.9	5.5	6.4	5.9	6.1	7.4
100 . . .	9.4	10.1	10.8	4.8	12.0	11.2
150 . . .	5.6	5.7	5.6	1.9	6.5	2.5
Pass 150 . . .	7.5	12.7	7.2	1.3	5.9	10.5
Total . . .	99.8	100.0	99.9	99.7	100.0	100.1

TABLE LXI.—*The Moulding Characteristics of the Rotten Rocks in Group C.*

Test-pieces of A.F.A. dimensions; rammed 10 times.

Moisture Content, %.	6.0.	7.0.	8.0.	9.0.	10.0.
<i>W4M, Dead Friars' Quarry</i> (Main Face).					
Bulk density, g./c.c. . .	1.70	1.72	1.74	1.76	1.78
Permeability No. . .	40.0	37.0	34.0	32.0	30.0
Green strength, lb./sq. in. .	21.8	21.0	20.2	19.2	18.4
Dry strength, lb./sq. in. .	140	170	200	230	260
<i>W5, Weather Hill Quarry.</i>					
Bulk density, g./c.c. . .	1.70	1.72	1.75	1.77	1.79
Permeability No. . .	40.0	38.0	36.0	34.0	32.0
Green strength, lb./sq. in. .	12.0	14.0	12.0	8.0	5.0
Dry strength, lb./sq. in. .	75.0	90.0	105	120	140
<i>W12, Sand Edge.</i>					
Bulk density, g./c.c. . .	1.74	1.78	1.82	1.84	1.86
Permeability No. . .	20.0	25.0	22.0	21.0	20.0
Green strength, lb./sq. in. .	22.0	20.0	15.5	12.0	9.0
Dry strength, lb./sq. in. .	120	140	160	180	200
<i>W1, Parkhead Quarry.</i>					
Bulk density, g./c.c. . .	1.78	1.80	1.82	1.84	1.86
Permeability No. . .	28.0	26.0	25.0	21.0	17.0
Green strength, lb./sq. in. .	31.5	30.0	25.0	19.0	15.5
Dry strength, lb./sq. in. .	130	150	175	200	225
<i>W9, Hisehope Reservoir.</i>					
Bulk density, g./c.c. . .	1.77	1.78	1.79	1.81	1.83
Permeability No. . .	29.0	29.0	28.0	27.0	26.0
Green strength, lb./sq. in. .	19.7	17.0	14.0	11.0	8.0
Dry strength, lb./sq. in. .	100	120	140	160	175
<i>W14, Baal Hill.</i>					
Bulk density, g./c.c. . .	1.77	1.80	1.83	1.85	1.87
Permeability No. . .	13.0	15.0	14.0	13.0	12.0
Green strength, lb./sq. in. .	25.0	24.0	19.5	15.0	11.5
Dry strength, lb./sq. in. .	180	215	250	285	320

TABLE LXII.—*The Refractoriness of the Rotten Rocks in Group C.*

A.F.A. test-pieces, rammed 10 times, fired at 1550° C. for 2 hr.

Source.	Appearance of Test-Piece.	Shrinkage, %.
W4M, Dead Friars' Quarry (Main Face).	Grey with brown mottling; slightly glazed surface.	5
W5, Weather Hill Quarry.	White with slight brown mottling; grains well fritted together.	Nil
W12, Sand Edge.	Grey with slightly glazed surface.	6
W1, Parkhead Quarry	White; grains well fritted together.	Nil
W9, Hisehope Reservoir.	White; grains well fritted together.	Nil
W14, Baal Hill.	Brown glazed surface; squatted.	...

green-strength/moisture curves (Fig. 81(c)) show differences similar to those observed in Group A; the curve for W4M, containing moderately pleochroic hydrobiotite, has a gentle gradient, while those for the other rocks in this group have steep gradients—a difference in accord with that observed in Group A. The dry-strength/moisture curves (Fig. 82(c)) have similar gradients; the gradient of the curve for W4M is slightly steeper than those for W1, W5, W9, and W12, and similar to that for W14. Data relating to Group C rocks are contained in Tables LX.—LXII.

Thus the green strength of the crushed rocks bonded with moderately or strongly pleochroic hydrobiotite is less sensitive to moisture variations than that of rocks bonded with the less pleochroic micas, and so are likely to be more satisfactory in foundry practice. The dry strength tends to increase more rapidly with the original moisture content for those rocks containing moderately or strongly pleochroic mica than for those containing less pleochroic mica.

All the rocks are sufficiently refractory for use in steel moulding-sand mixes, particularly as, in most instances, they would be mixed with a high-silica sand in order to increase their permeability.

V.—THE ROTTEN ROCKS IN FOUNDRY PRACTICE.

Rotten rocks from a number of quarries in this area are supplied milled under the name of Derwent Moulding Sand to several nearby steel foundries. The milled rock from Parkhead Quarry (W1) is employed in steel foundries in north-east England and as far south as Sheffield. The rock from Viewly Hill Quarry (W7) has also been used on a small scale in steel foundries.

Some time ago trials were made in a Sheffield foundry in order to compare the behaviour of the sericite- and hydrobiotite-bonded sands. The comparison is of interest because it illustrates the differences due principally to the differences in the constitution of the bond. The sands formed the basis of the mixes used for dry-sand moulds for 500-lb. bomb castings. The mixes had the following compositions and properties:

	Mix A.	Mix B.
Sericite-bonded sand, %	50	...
Hydrobiotite-bonded sand, % . . . . .	...	50
High-silica sand, %	50	50
Moisture, %	5.8	5.8
Bulk density, g./c.c.	1.72	1.72
Permeability No.	125	110
Green strength, lb./sq. in.	7.5	9.6
Dry strength, lb./sq. in.	41	98

(A.F.A. test-pieces, rammed 10 times.)

The high-silica sand was fairly coarse-grained; it was added mainly in order to increase the permeability of the mixes and so to facilitate the drying out of the moulds.

The moisture content was as high as the drying stoves could cope with in the normal drying time; this content was employed in order to obtain as high a dry strength as possible. Under these conditions, Mix *A* did not feel so plastic as Mix *B*. The green strength of Mix *A* was lower than that of Mix *B*; as the moulds of the former were lifted off the pattern, the edges tended to break away. This did not occur with the moulds of the latter mix.

The moulds were painted with silica paint and dried in accord with the usual practice at this foundry. The Mix *B* moulds were cast alternately with the Mix *A* moulds and from the same ladle, that is, they were cast at a slightly higher and a slightly lower temperature than Mix *A* moulds. On stripping it was found that most of the surface of each bomb cast in Mix *A* was rough and there was much burnt-on sand near the runner. The bombs cast in Mix *B* parted easily from the sand, leaving a smooth skin except close to the runner; there a small amount of sand was burnt on to the castings. Test-pieces of the two mixes were fired at 1550° C. for 2 hr. Mix *B* showed marked fritting, whereas Mix *A* showed only slight fritting. The difference in the skin imparted to the casting is due to the development of a slagged layer of sand against the casting when the hydrobiotite-bonded sand was used.

Thus, under these conditions, sands bonded with strongly pleochroic hydrobiotite appear to be more satisfactory than those bonded with sericite.

VI.—CONCLUSIONS.

Rotten-rock moulding sands suitable for use in steel foundries are exposed at many localities in the Fell country of Durham and south Northumberland. Most of these rocks are composed of quartz and secondary mica, though some contain felspar or kaolinite in addition.

The secondary mica varies in composition; in some rocks most of the mica is strongly pleochroic, probably because of its high iron content, and may be referred to the hydrobiotite group. Progressively less pleochroic varieties predominate in the other rocks examined. In some of the rocks the mica shows little or no pleochroism and may be referred to the sericite group.

This distinction is an important one, for the moulding characteristics of the sands are closely related to the constitution of the bonding minerals. Sands bonded with the more pleochroic varieties of hydrobiotite are to be preferred to those bonded with the less pleochroic varieties or with sericite because: (1) The gradient of their green-strength/moisture curve is more gentle, that is, their green strength is less sensitive to variations in moisture content; and (2) their refractoriness is slightly lower, so that, under certain conditions, they may form a slagged layer against the casting; this layer strips readily and imparts a smooth skin to the casting.

APPENDIX.—Detailed Description of the Rocks.

W1, Parkhead Quarry. (Messrs. Durhills, Ltd., Stanhope.)

Situation.—Adjoining Stanhope-Edmondbyers road, 2½ miles north of Stanhope.

Transport Facilities.—Adjoins L.N.E. mineral railway.

Petrology.—The general structure of the beds exposed in the quarry face has already been given in Part 4. The rock is friable and has a mottled

appearance due to sporadic limonite staining; the general colour is white, or varies from pale to deep brown, according to the intensity of this staining. A few flakes of muscovite occur on some of the bedding planes. The grain-size is predominantly medium, though coarse- and fine-grained layers do occur.

This grit is composed of quartz and secondary mica, together with a small amount of kaolinite. Many of the quartz grains have pronounced strain shadows; inclusions are conspicuous in many of the grains and tend to be linearly arranged. Grains of quartzite are rare. The grain outlines are irregular, but have not become frilled. There are a few large flakes of limonite-stained hydrobiotite, pleochroic from pale brown to colourless.

The secondary mica occurs as aggregates of flakelets and wisps. Most of the aggregates are very slightly pleochroic; a few are moderately pleochroic. Kaolinite forms the central part of a few of the aggregates.

Quartzitic aggregates are fairly well developed, in many cases, with micaceous films between the grains. The bulk of the secondary mica is interstitial to these aggregates.

W2, Disused Quarry, Nr. Waskerley. (Messrs. Durhills, Ltd., Stanhope.)

Situation.—Disused quarry adjoining L.N.E. mineral railway, $1\frac{1}{2}$ miles west of Waskerley village.

Petrology.—This quarry is very shallow. Only weathered debris was available, as the bedrock was hidden under drift. The sample is a friable, medium-grained grit, the bond of which is stained brown with limonite. It is composed of quartz and secondary mica, together with a little kaolinite. The quartz grains are frilled and many of them have pronounced strain shadows. Linearly arranged inclusions in the quartz grains are not uncommon. There are a few large flakes of hydrobiotite, pleochroic from pale brown to colourless.

The secondary mica is in part opaque, owing to the heavy limonite staining; the mica forms aggregates of wisps and flakes. These aggregates show moderate pleochroism in shades of brown.

Quartzitic aggregates with intricate sutures are fairly well developed with secondary mica interstitial to the aggregates. The successive films which occur between some of the quartz grains in the aggregates are fairly heavily stained with limonite.

W3, Disused Quarry, Nr. Waskerley. (Messrs. Durhills, Ltd., Stanhope.)

Situation.—Disused quarry 150 yd. north-west of locality W2, and about $1\frac{1}{2}$ miles west of Waskerley village.

Transport Facilities.—About 200 yd. of rough road connects the quarry to the L.N.E. mineral railway.

Petrology.—The rock exposed in the quarry face is medium- to coarse-grained, friable grit, almost white, except for a slight amount of brown limonite staining along the joints and major bedding planes. It is composed of quartz, secondary mica, and kaolinite.

Many of the grains are strained and contain linearly-arranged inclusions. Quartzitic grains are abundant; the outlines of the grains are irregular, but show no sign of frilling. There are more large flakes of hydrobiotite, pleochroic from pale brown to colourless, than in most of the rotten rocks. Large muscovite flakes are conspicuous.

The secondary mica forms felted aggregates, and is slightly pleochroic. The centres of many of these aggregates are formed of kaolinite.

Quartzitic aggregates are not common, and the majority of the quartz grains are bonded together by the secondary mica.

W4, Dead Friars' Quarry. (Mr. J. J. S. Wilkinson, Blanchland.)

Situation.—Quarry adjoining the Stanhope-Blanchland road 4 miles north-north-west of Stanhope.

Transport Facilities.—About 2 miles by good road from the L.N.E. mineral railway at Parkhead. At present the rock is taken about 6 miles by road to Burn Hill Station, where it is milled before loading on to rail.

Petrology.—The false-bedding, characteristic of these grits, is well exposed in this quarry. The main face (about 15 ft. high) opposite the quarry entrance is being worked in a medium-grained, friable grit, which has a mottled appearance due to limonite staining of parts of the white bond; when moistened, the white bond takes on a faint green tint. To the right of the quarry entrance is a second face, 5-10 ft. high, but in a lens of coarse-grained, friable grit, white, with slight brown mottling, except where it has been deeply stained with brown limonite close to the joints and bedding planes.

The rock, from both faces, is composed of angular quartz grains, together with secondary mica, and, occasionally, kaolinite. The majority of the quartz grains show no signs of strain shadows; there are several grains of quartzite, of which a few are well banded. Inclusions, where present, are arranged at random. Cracked grains are rare. Large grains of hydrobiotite which have opened along the cleavage planes are not uncommon; they exhibit marked pleochroism in shades from pale brown to almost colourless.

The secondary mica forms flakelets and wisps which have a rather felted structure. There are no obvious pseudomorphs after feldspar. The wisps near the quartz grains are in many cases arranged parallel to the grain surfaces. Most of the secondary mica is slightly pleochroic in the samples from the right face (W4R), and moderately pleochroic in shades of brown in that from the main face (W4M). Aggregates of kaolinite are rare in the sample from the right face and none was detected in that from the main face.

The microstructure is characterized by quartzitic aggregates separated by interstitial secondary mica. Some of the secondary mica forms films between the quartz grains in the aggregates.

W5, Weather Hill Quarry. (Mr. Hobson; output taken by General Refractories, Ltd.)

Situation.—Adjoining Stanhope-Edmondbyers road, 1½ miles north of Stanhope.

Transport Facilities.—Adjoins the L.N.E. mineral railway.

Petrology.—This quarry is rather shallow, and the face nowhere exceeds 15 ft. in height. The rock is medium- to fine-grained, friable grit, varying in colour from white to pale brown. Muscovite flakes are conspicuous on some of the bedding planes.

In the microsection, a frequent alternation of coarse- and fine-grained layers is conspicuous. It is composed of quartz and secondary mica, together with a few grains of feldspar. The quartz grains are angular but frilled outlines are rare. Many of the quartz grains have pronounced strain shadows, and contain linearly arranged inclusions. Quartzitic grains are rare. The rock is unusual in containing recognizable grains of feldspar, most of which appear to be microcline. Large flakes of faintly pleochroic hydrobiotite are not uncommon. The secondary mica forms felted aggregates, and is slightly pleochroic from light to dark brown.

The microstructure is characterized in some parts of the rock by quartzitic aggregates in which the grains are closely sutured together and by interstitial secondary mica; in other parts the quartz grains are sheathed with secondary mica.

W6, Harperley Hill Quarry. (General Refractories, Ltd.)

Situation.—Adjoining road midway between Stanhope and Crook.

Transport Facilities.—The rock is taken 3 miles by road to Wolsingham, where it is milled before being put on rail.

Petrology.—Medium- to coarse-grained, friable grit is exposed in the quarry. The rock is brown, owing to limonite staining of the bond.

Quartz and secondary mica are the principal constituents of this grit. The quartz grains are angular, but fritted outlines are rare. Some of the grains exhibit strain shadows and contain linearly-arranged inclusions. Grains of quartzite are not uncommon. There are a few large grains of very pale brown hydrobiotite showing slight pleochroism.

The secondary mica forms felted aggregates and is slightly pleochroic in shades of light brown. It is stained locally with limonite so that it is nearly opaque.

The microstructure is characterized by quartzitic aggregates with interstitial secondary mica.

W7, Viewly Hill Quarry. (Mr. Thompson.)

Situation.—Adjoining Wolsingham-Consett road, $2\frac{1}{2}$ miles from Wolsingham.

Transport Facilities.—About 2 miles by road from Tow Law Station.

Petrology.—About 15 ft. of soft grit is exposed below 12–15 ft. of glacial drift in this quarry face. The grit is, for the most part, medium-grained, though coarse layers an inch or so in thickness are not uncommon. The rock has a finely mottled appearance, in shades of dull green and brown; the former colour is due to hydrobiotite, while the latter is due to limonite. Except for the topmost foot of rock, this grit is friable, like the other rotten rocks. The topmost foot is much more compact, owing to a higher bond content, and has a deep green colour; because of its compact texture, this rock is more difficult to crush than most of the rotten rocks. Muscovite flakes are rare except on a few of the bedding planes.

Quartz and secondary mica are the principal constituents. The quartz grains are unstrained and contain a few scattered inclusions. Grains of quartzite are rare. The grains are angular, but fritted outlines are rare. The secondary mica is greenish-brown and strongly pleochroic: it occurs as finely felted aggregates.

Quartzitic aggregates are poorly developed and the majority of the quartz grains are sheathed in secondary mica.

W8, Feldon Carrs.

Situation.—On the east side of Stanhope-Edmondbyers road, $5\frac{1}{2}$ miles from Stanhope.

Transport Facilities.—About 2 miles by road from the L.N.E. mineral railway at Parkhead.

Petrology.—This is a pale-brown or cream-coloured, friable grit; for the most part fine-grained, though coarse-grained layers $\frac{1}{8}$ – $\frac{1}{4}$ in. thick occur at frequent intervals. These coarse layers contain a few muscovite flakes.

This grit is composed mainly of quartz grains together with secondary mica. The quartz grains have well-marked strain shadows, though they contain few inclusions and even those have a random arrangement. There are a few large grains of hydrobiotite showing strong pleochroism in shades of brown. The secondary mica is wispy and has a felted structure; it exhibits changed relief rather than pleochroism on rotating the polarizer. There are no obvious pseudomorphs after feldspar.

The microstructure is characterized by numerous closely sutured quartzitic aggregates separated by aggregates of secondary mica. The

quartz grains are rather corroded, and the wisps of mica follow the pitted surfaces of the quartz grains closely.

W9, Hisehope Reservoir.

Situation.—Adjoining moorland road to Hisehope Reservoir, 500 yd. to the north of Stanhope-Edmondbyers road, $1\frac{1}{2}$ miles west of Waskerley.

Transport Facilities.—About 2 miles by road from the L.N.E. mineral railway at Waskerley.

Petrology.—This is a medium- to fine-grained, pale-brown grit. Muscovite flakes occur on some of the bedding planes. Near the joints and bedding planes, light and dark brown bands appear, parallel to the bounding surface, due to rhythmic variation in the limonite staining.

Quartz and secondary mica are the principal constituents. The majority of the quartz grains are unstrained and contain few inclusions. Quartzitic grains are rare. The grains are angular, but their outlines are rarely frilled. There are a few large flakes of hydrobiotite, pleochroic from pale brown to colourless. The secondary mica forms felted aggregates of fine wisps, and exhibits change of relief rather than pleochroism. The centres of some of the aggregates are composed of kaolinite.

Quartzitic aggregates are fairly well developed, with the secondary mica interstitial to these aggregates. Micaceous films separate the grains in some of the aggregates.

W10, Millstone Rigg.

Situation.—500 yd. east-south-east from Weather Hill Engine on the Stanhope-Edmondbyers road, 2 miles from Stanhope.

Transport Facilities.—L.N.E. mineral railway at Weather Hill.

Petrology.—This is a medium- to coarse-grained, brown, very friable grit. It is composed of quartz and secondary mica, together with some kaolinite. Most of the quartz grains show well-marked strain shadows and contain linearly arranged inclusions. Quartzitic grains have an irregular outline due to corrosion. There are a few flakes of hydrobiotite, pleochroic from pale brown to colourless, which have split along cleavage planes.

The secondary mica occurs as felted aggregates in which the central portions show slight pleochroism, though their marginal portions are usually strongly pleochroic in shades of brown. The central portion of some of the aggregates is composed of kaolinite.

Quartzitic aggregates are not well developed, and secondary mica forms the main bond of the rock.

W11, Bridge Old Quarry.

Situation.—Two miles east of Stanhope.

Transport Facilities.—Two miles from Stanhope Station.

Petrology.—This is a medium- to coarse-grained, brown, friable grit. The bond has been almost entirely removed from the more weathered portion of the sample. The grit is composed of quartz and secondary mica. Most of the quartz grains exhibit strain shadows, and contain linearly arranged inclusions. Quartzitic grains are not uncommon. The grains are angular, but frilled outlines are rare. There are a few grains of pale brown hydrobiotite, showing distinct pleochroism. The secondary mica occurs as aggregates of flakelets and wisps, and is slightly pleochroic.

The microstructure is characterized by quartzitic aggregates with the secondary mica filling the interstices.

W12, Sand Edge.

Situation.—Diggings $\frac{3}{4}$ mile north of Redmires Farm, $3\frac{1}{4}$ miles north of Wolsingham.

Transport Facilities.—4 miles by road from Wolsingham Station.

Petrology.—This is a medium-grained grit with a few thin coarse-grained layers. Parts of the grit are almost white, except for a little sporadic limonite staining. Other parts are finely mottled in shades of dull green and brown; this mottling is particularly marked in moist specimens, and is due to hydrobiotite and limonite. A few muscovite flakes occur on some of the bedding planes.

The grit is composed of quartz and secondary mica. The quartz grains show well-developed strain shadows and contain numerous linearly-arranged inclusions. Quartzitic grains are conspicuous. The grains are angular, but frilled outlines are not common. There are a few grains of hydrobiotite, pleochroic from pale brown to colourless. The secondary mica occurs as felted aggregates, which show slight pleochroism in shades of brown.

Quartzitic aggregates are fairly well developed, and are separated by the secondary mica.

W13, Redmires.

Situation.—Quarry 400 yd. north of Redmires Farm, 3 miles north of Wolsingham.

Transport Facilities.—4 miles by road from Wolsingham Station.

Petrology.—This is a rather coarse-grained, friable grit, varying in colour from white to brown according to the intensity of the limonite staining. Muscovite flakes are rare.

This grit is composed of quartz grains and secondary mica. The majority of the quartz grains are unstrained and have an extremely frilled outline due to corrosion. Quartzitic grains are rather conspicuous. Linearly arranged inclusions in the quartz grains are more conspicuous than in many of the rotten rocks. There are a few large flakes of hydrobiotite, which show marked pleochroism from brown to colourless. The secondary mica forms felted aggregates of wisps which exhibit change of relief rather than pleochroism.

The microstructure is characterized by intricately sutured quartzitic aggregates with secondary mica filling the interstices between adjacent aggregates.

W14, Baal Hill.

Situation.—Quarries $1\frac{1}{2}$ miles north of Wolsingham, on the west side of the moorland road running north from Wolsingham Farm.

Transport Facilities.—2 miles by road from Wolsingham Station.

Petrology.—This is a medium-grained, brown, friable grit. Muscovite flakes occur on some of the bedding planes. The grit is composed mainly of quartz, secondary mica, and kaolinite. Many of the quartz grains show strain shadows and contain linearly arranged inclusions. Quartzitic grains are not uncommon. The grains are angular and many of them have frilled outlines. There are a few flakes of pale brown hydrobiotite. Most of the secondary mica shows change of relief rather than pleochroism. The mica forms felted aggregates, frequently with cores of kaolinite.

The microstructure is characterized by quartzitic aggregates separated by interstitial secondary mica and kaolinite.

W15, Cleugh.

Situation.—Quarry 1 mile south-east of Tow Law.

Transport Facilities.— $1\frac{1}{2}$ miles by road from Tow Law Station.

Petrology.—The bulk of this rock is medium- to fine-grained, though thin, coarse-grained layers do occur; it is cream-coloured. Muscovite flakes occur on some of the bedding planes.

In the microsection, variation in grain-size from layer to layer is conspicuous. The rock is composed of quartz and secondary mica. Only a

few quartz grains show strain shadows. Grains of quartzite and grains with inclusions are rare. Some of the quartz grains have developed fine cracks. There are a few large grains of hydrobiotite, pleochroic from pale brown to almost colourless, which have split along cleavage planes.

The secondary mica occurs as felted aggregates of wisps, and exhibits change of relief rather than pleochroism. Quartzitic aggregates are not well developed and mostly include micaceous films between their constituent quartz grains. The secondary mica envelops many of the quartz grains and forms the main bond of the rock.

W16, Apperley.

Situation.— $\frac{1}{2}$ mile south-south-west of Apperley Farm, $2\frac{1}{2}$ miles south of Stocksfield.

Transport Facilities.—3 miles by road from Stocksfield Station.

Petrology.—This is a coarse-grained, brown, friable grit. It is composed of quartz, secondary mica, and kaolinite. Many of the quartz grains exhibit strain shadows and contain linearly-arranged inclusions. Quartzitic grains are not uncommon. The grains are angular, mostly with frilled outlines. There are a few large flakes of slightly pleochroic hydrobiotite. Most of the secondary mica exhibits change of relief rather than pleochroism; it forms rather coarse, felted aggregates. The kaolinite is more abundant than in most of the rotten rocks and forms the central portions of many of the micaceous aggregates.

Quartzitic aggregates are fairly well developed, with the secondary mica and kaolinite occupying the interstices between these aggregates.

Part 10.—The Rotten-Rock Moulding Sands of the Midland Valley of Scotland.

(Figs. 94 to 96 = Plate VIII.)

SYNOPSIS.

A brief account is given of the moulding characteristics of several typical Scottish rotten rocks. Their characteristics are similar to those of the Durham rotten rocks. In one sample, the bond has been reduced to kaolinite; such advanced weathering reduces the strength markedly.

I.—INTRODUCTION.

THE rotten-rock moulding sands (or "rock sands") of the Midland Valley of Scotland have long been used in the nearby foundries. They are friable sandstones which can easily be broken down by milling to form naturally-bonded moulding sands. These sands have a high green strength and a rather low permeability; in foundry practice, they are usually mixed with a high-silica sand to increase their permeability and refractoriness.

Professor P. G. H. Boswell * described the geological occurrence of a number of the Scottish rotten rocks and gave mechanical and chemical analyses of several of them. Later, J. G. A. Skerl gave a short account of the moulding properties of three Scottish rotten rocks; he stated that their properties are largely dependent on the mineralogical constitution of their bonding material, though he did not develop this relationship. These two accounts appear to be the only important published work on the use of the Scottish rotten rocks as moulding sands.

The Scottish rotten rocks discussed in this account have much in common with Durham rotten rocks described in Part 9. They are finer in

* "British Resources of Refractory Sands," 1918, p. 115 *et seq.*

grain and their bond rarely includes markedly pleochroic hydrobiotite. The rotten rocks described here are principally of interest in relating moulding characteristics to the mineralogical constitution of the bond for rocks bonded with kaolinite or with secondary mica rarely exhibiting more than slight pleochroism.

The samples were obtained from the localities given in Table LXIII.

TABLE LXIII.—*Index to Localities.*

Ref. No.	Source.	Location.
X1	Dullatur.	Adjoining Dullatur Station on the Glasgow-Edinburgh (L.N.E.) railway line.
X2	Avenuehead.	1½ miles from Glenboig station on the north-eastern side of the Glenboig-Kirkintilloch railway line.
X3	Drumcavil (White and Yellow).	One mile north-west of Glenboig Station, close to the Glenboig-Kirkintilloch railway line.
X4	Carlops.	Near to West Linton, 10 miles north-east of Peebles.

II.—STRATIGRAPHY.

The rotten rocks occur in the Limestone Series, the Millstone Grit Series, and the Coal Measures of the Carboniferous System exposed in the Midland Valley. The examples described in this paper were obtained from horizons in the Millstone Grit Series.

III.—PETROLOGY.*

The rotten rocks described here are composed mainly of quartz, secondary mica, and kaolinite. They are white or grey, friable sandstones, except where they have been stained brown by limonite. Professor Boswell, discussing their origin (*loc. cit.*), describes them as sandstones "containing what were once abundant felspar grains derived from the Archaean felspar-bearing rocks in the north-west which formed the Carboniferous land area. Felspar, by the leaking-out of part of its alkalies, decomposes to mica and excess of silica; when the alkalies have entirely disappeared, kaolin (china-clay) results. The production of micas is frequently a 'resting-stage' in the process and it is usual to find both micas and kaolin together at the same time."

The quartz grains are angular and, in some instances, have frilled outlines due to corrosion. Some of the grains show signs of permanent strain, either by undulose extinction or by the traces of shear planes marked by bubble inclusions, that is, by linearly-arranged inclusions in the section.

A few grains of almost unaltered microcline felspar occur in some of the rocks.

Flakes of the primary mica, muscovite, are to be found in most of the rotten rocks. No unaltered biotite was seen, though there are pseudomorphs after biotite. These pseudomorphs are composed of hydrobiotite, or, in a few instances, of a green mineral which may be a chlorite. In some of the rocks, there are aggregates of pennine chlorite. The association of biotite and chlorite raises an interesting problem concerning the conditions governing the formation of these two secondary minerals. Some of the chlorite, at least, has been derived from biotite and so has all the hydrobiotite. No chlorite was detected in the Durham rotten rocks (*see* Part 9), though hydrobiotite pseudomorphs after biotite were evident in

* Detailed descriptions of the rocks are given in the Appendix.

most of them. It is probable that the chlorite and hydrobiotite were formed at different stages in the history of the Scottish rotten rocks.

Apart from these large mica flakes, the rocks contain a considerable proportion of finely divided secondary mica. This mica occurs as aggregates of flakes the pattern of which resembles basket-work. The mica is either a slightly pleochroic hydrobiotite or more commonly sericite. The polarization colours of the sericite in the several rocks suggesting small variations in the potash-hydroxyl ratio, vary slightly.

The kaolinite forms typical vermicular aggregates which may include a few wisps of sericite.

The microstructure depends on the development of quartzitic aggregates, that is, of aggregates of interlocking quartz grains. The development of these aggregates has been described in the earlier parts of this series of papers.

The microstructure of several of the Scottish rotten rocks has been described by the Geological Survey.* It depends mainly on the extent to which the shape of the quartz grains has been altered by corrosion and secondary silicification so that the grains interlock to form quartzitic aggregates. Ideally the quartz grains should be separated from each other by the secondary mica and kaolinite, as the rock is then most easily reduced to an even-grained sand. The quartzitic aggregates are not easily broken down by milling and persist in the milled sand as angular fragments, large enough to be detrimental in moulding. The microstructures of three of the rocks are illustrated by Figs. 94-96.

The Avenuehead rock (Fig. 94) contains a few poorly developed quartzitic aggregates set in a matrix of secondary mica having rather low polarization colours. The mica is almost colourless and is a typical sericite.

The Dullatur rock (Fig. 95) is similar to the Avenuehead rock, but rather coarser. The flakes of secondary mica are larger and exhibit rather high polarization colours.

The Carlops rock (Fig. 96) contains very few quartzitic aggregates. Most of the interstices between the quartz grains are filled with kaolinite.

The proportions of bond in these rocks are given in Table LXIV.

IV.—PHYSICAL CHARACTERISTICS.

The five rock sands may be separated into two groups according to grain-size. The first group includes the Dullatur and Carlops sands, both of which are medium-grained. They illustrate the difference in the physical characteristics due to a sericite bond and to a kaolinite bond respectively. Their physical characteristics are given in Tables LXV. and LXVI. and their strength/moisture curves are shown in Fig. 83. It will be seen that the green-strength/moisture curves have similar gradients; the Carlops sand has a far lower green strength, for a given moisture content, than the Dullatur sand, though the two rocks contain the same proportion of bond and have similar mechanical gradings. The dry-strength/moisture curves show even more marked differences; for a given moisture content, the Carlops sand has a much lower dry strength than the Dullatur sand. On the other hand, the Carlops sand when fired at 1550° C. for 2 hr., is decidedly more refractory than the Dullatur sand.

The second group includes the Avenuehead and two Drumcavil sands; all three are fine-grained. Their physical characteristics are given in Tables LXVII.-LXIX. and their strength/moisture curves are shown in Fig. 84. The difference between the Drumcavil Yellow and Grey sands is probably

* "The Geology of the Glasgow District," p. 258 &c., *Memoirs of the Geological Survey of Great Britain*, 1925.

due to the limonite associated with the sericite in the bond of the yellow sand. The Drumcavil sands are rather less refractory than the Avenue-head sand; otherwise there is little difference in the characteristics of the three sands.

TABLE LXIV.—*Micrometric Analyses of the Scottish Rotten Rocks.*

Ref. No.	Source.	Quartz, %.	Bonding Minerals, %.
X1	Dullatur	71.0	29.0
X2	Avenuehead	65.5	34.5
X3	Drumcavil Grey	64.0	36.0
	" Yellow	65.0	35.0
X4	Carlops	69.5	30.5

TABLE LXV.—*The Physical Characteristics of Dullatur Rock Sand.*

MECHANICAL GRADING.						
Percentage Retained on B.S.I. Sieve No.—	As Received.	Sand Grade Only.				
5	0.2	0.2	<i>By Elutriation :</i> Medium sand 50.5 Fine sand 30.2 Silt 10.0 Clay 9.3			
8	0.5	0.6				
10	0.2	0.3				
16	4.5	4.5				
22	7.3	6.8				
30	13.3	12.2				
44	18.2	17.1				
60	21.0	21.8				
72	10.3	12.8				
100	11.1	15.0				
150	6.2	8.7				
Pass 150	7.2	...				
Total	100.0	100.0				

MOULDING CHARACTERISTICS.						
Moisture content, % .	5.0	6.0	7.0	8.0	9.0	10.0
<i>A.F.A. test-pieces, rammed 3 times.</i>						
Bulk density, g./c.c.	1.84	1.85	1.85	1.86	1.87	1.88
Permeability No.	74	70	65	57	50	45
Green strength, lb./sq. in.	10.5	9.5	8.4	8.0	7.6	7.3
Dry strength, lb./sq. in.	80	105	130	155	175	200
<i>A.F.A. test-pieces, rammed 10 times.</i>						
Bulk density, g./c.c.	1.92	1.93	1.94	1.95	1.96	1.98
Permeability No.	27	25	24	23	20	19
Green strength, lb./sq. in.	20.0	18.5	16.3	14.3	12.5	11.2
Dry strength, lb./sq. in.	140	170	205	235	270	300

REFRACTORINESS.
A.F.A. test-pieces, rammed 10 times, were fired at 1550° C. for 2 hr. The test-pieces were pale brown, glazed, and rather distorted.

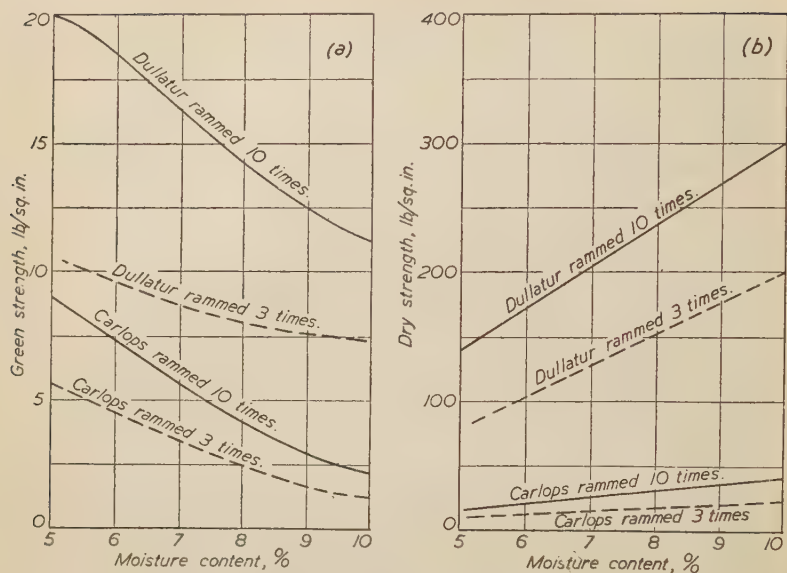


FIG. 83.—Green Strength (a) and Dry Strength (b) of Dullatur and Carlops Rotten-Rock Moulding Sands. A.F.A. test-pieces.

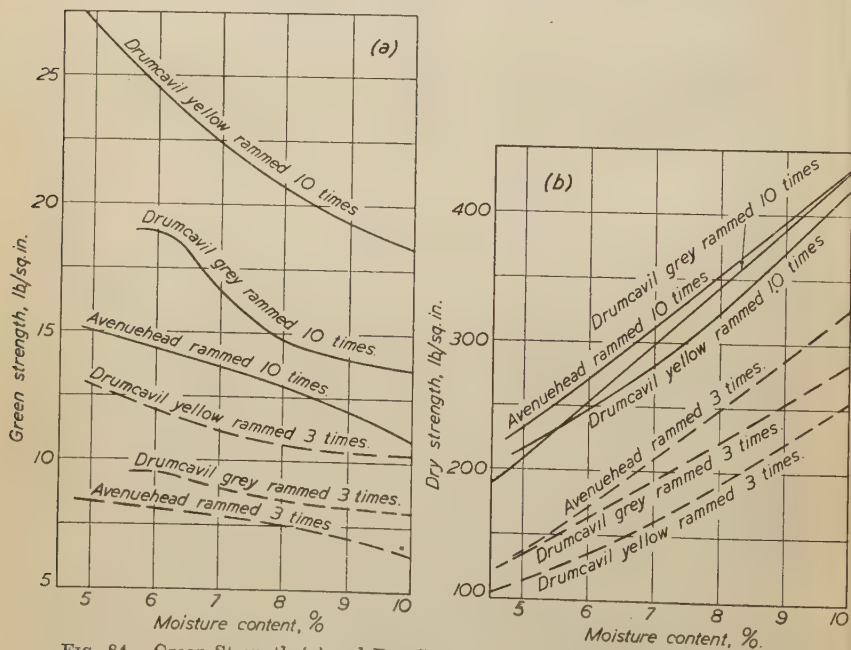


FIG. 84.—Green Strength (a) and Dry Strength (b) of Avenuehead and Drumcavil Rotten-Rock Sands. A.F.A. test-pieces.

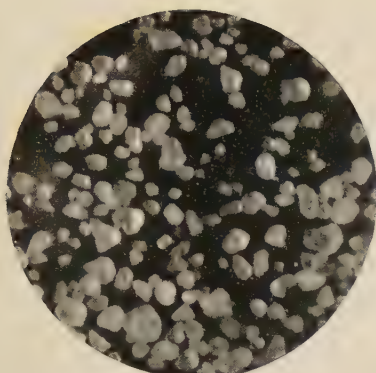


FIG. 85.—Recent Sand.

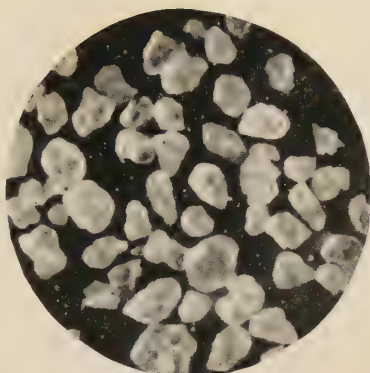


FIG. 86.—Spilsby Sandstone.

FIGS. 85 and 86.—Typical Samples of Sands from the Lincolnshire Wolds. $\times 15$, reflected light.

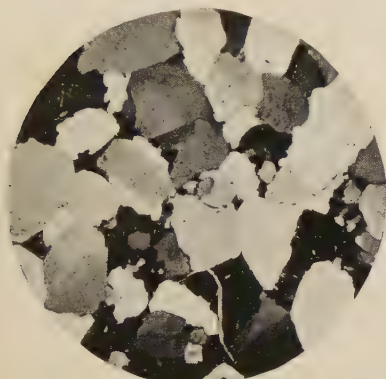


FIG. 87.—Coarse White Grit.

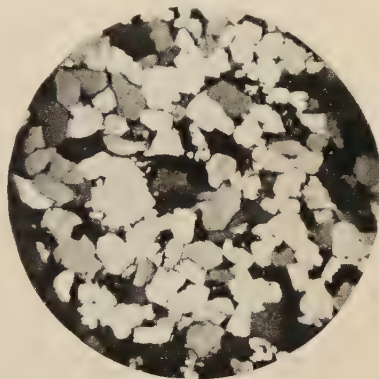


FIG. 88.—Fine White Sandstone.

FIGS. 87 and 88.—Quartzitic Sandstones from Low Woods Quarry. $\times 30$, crossed nicols.

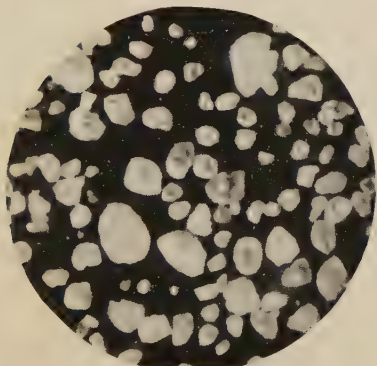


FIG. 89.—Caergwile Sand.

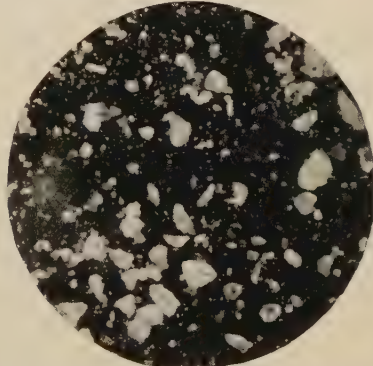


FIG. 90.—Crushed Compact Bwlch Gwyn Rock.

FIGS. 89 and 90.—Cefn-y-Fedw Sandstones. $\times 15$, reflected light.

(Micrographs reduced to four-fifths linear in reproduction.)

[Davies & Rees.
To face p. 112 p.]

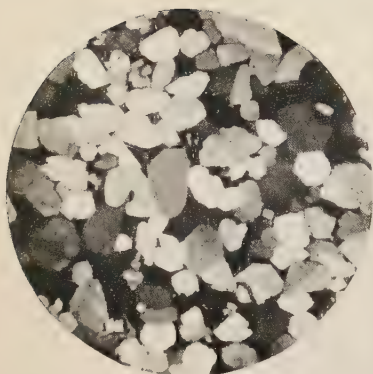


FIG. 91.—Grains corroded at points of contact.

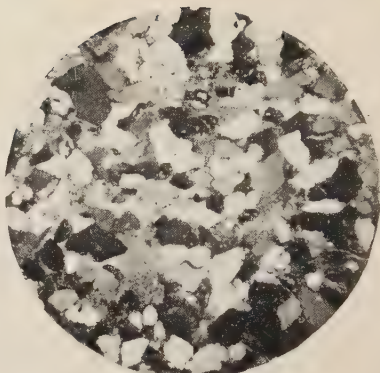


FIG. 91.—Avenuehead Rock.

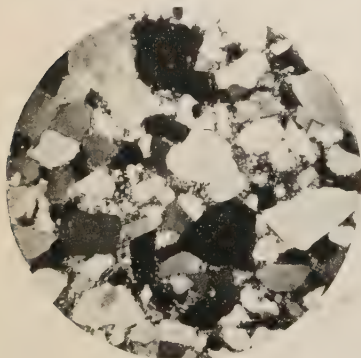


FIG. 92.—Secondary silica deposited as granules in pores.

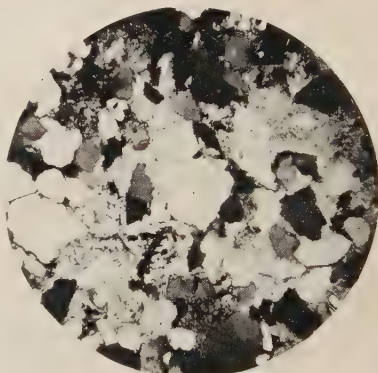


FIG. 95.—Dullatur Rock.



FIG. 93.—Secondary silica attached to quartz grains.

FIGS. 91 to 93.—Types of Secondary Solidification in Cefn-y-Fedw Sandstones. $\times 30$, crossed nicols.

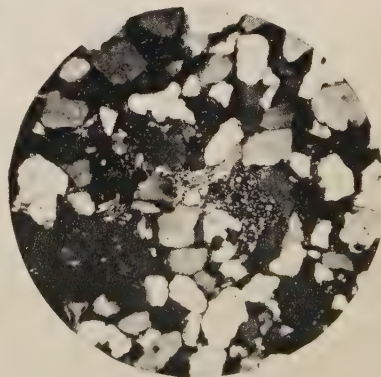


FIG. 96.—Carlops Rock.

FIGS. 94 to 96.—Scottish Rotten-Rock Moulding Sands. $\times 30$, crossed nicols.

(Micrographs reduced to four-fifths linear in reproduction.)

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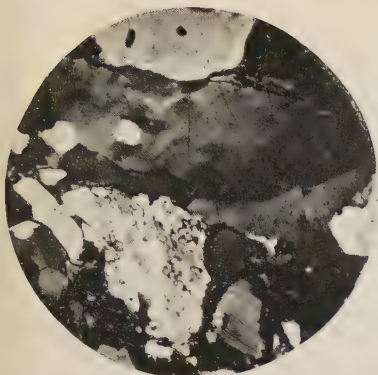


FIG. 97.—Quartz grain showing strain shadows and linearly-arranged inclusions. Crossed nicols.

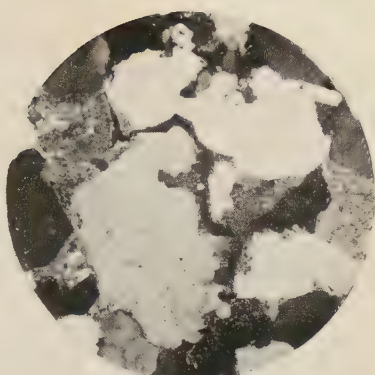


FIG. 98.—Corroded quartz grain showing frilling. Crossed nicols.

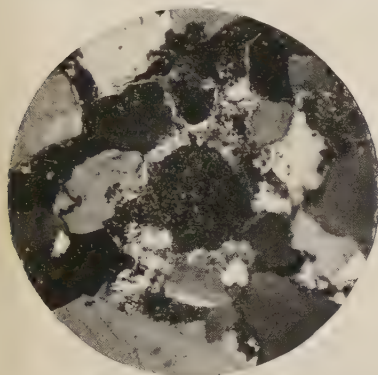


FIG. 99.—Kaolin aggregate. Crossed nicols.

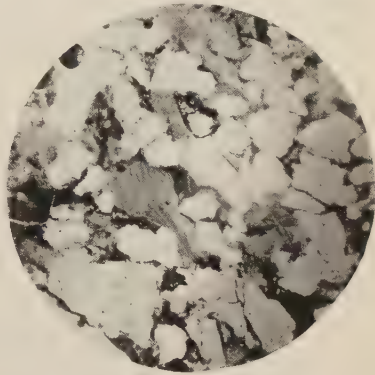


FIG. 100.—Large flakes of hydrobiotite in rotten rock. Crossed nicols.

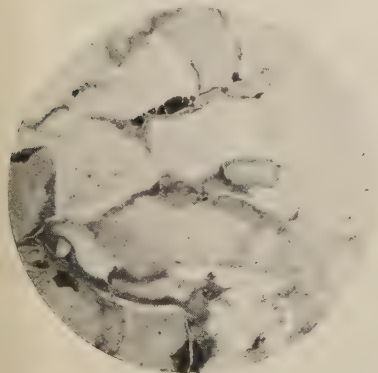


FIG. 101.—Aggregates of secondary mica. Ordinary light.

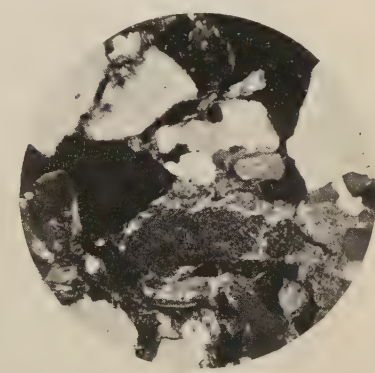


FIG. 102.—Same field as Fig. 101, but through crossed nicols.

FIGS. 97 TO 102.—Rotten-Rock Moulding Sands of Durham and South Northumberland. $\times 50$.
(Micrographs reduced to four-fifths linear in reproduction.)

[Davies & Rees.

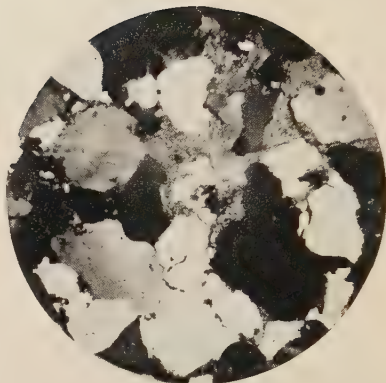
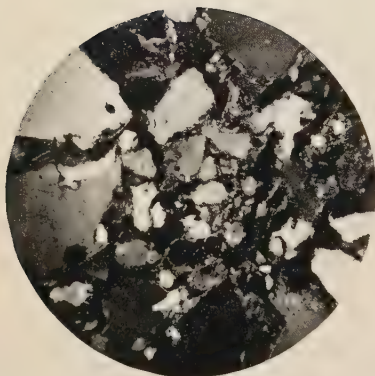


FIG. 103.—Quartz grains separated by film of bonding material.

FIG. 104.—Quartz grains sutured together; bonding material interstitial.

FIGS. 103 and 104.—Types of Microstructure Shown by Durham Rotten Rocks. $\times 30$, crossed nicols.
(Micrographs reduced to four-fifths linear in reproduction.)

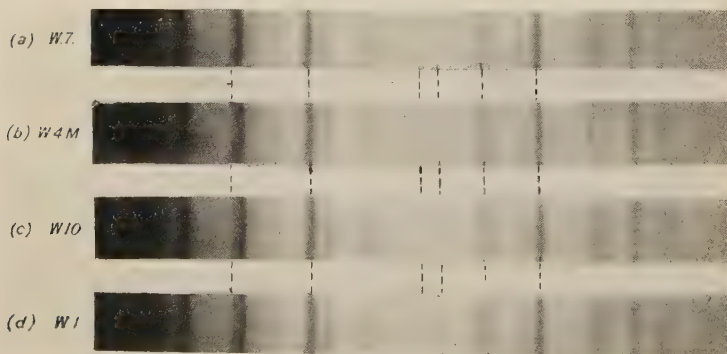


FIG. 105.—X-Ray Diffraction Patterns of the Secondary Micas of the Durham Rotten Rocks. Both mica and quartz lines are present in the patterns; the mica lines are indicated by the dotted connecting lines.

TABLE LXVI.—*The Physical Characteristics of Carlops Rock Sand.*

MECHANICAL GRADING.			
Percentage Retained on B.S.I. Sieve No.—	As Received.	Sand Grade Only.	
5	0.0	0.0	
8	0.2	0.5	
10	0.3	0.4	
16	8.3	6.0	<i>By Elutriation :</i>
22	6.9	8.3	Medium sand
30	7.0	8.0	Fine sand
44	12.6	12.3	Silt
60	23.3	26.3	Clay
72	14.9	16.2	
100	10.5	12.0	
150	11.5	10.0	
Pass 150	4.5	...	
Total	100.0	100.0	100.0

MOULDING CHARACTERISTICS.

Moisture content, %	5.0	6.0	7.0	8.0	9.0	10.0
<i>A.F.A. test-pieces, rammed 3 times.</i>						
Bulk density, g./c.c. . . .	1.81	1.82	1.83	1.84	1.85	1.86
Permeability No. . . .	55	52	50	49	47	45
Green strength, lb./sq. in. . .	5.6	4.5	3.4	2.4	1.7	1.2
Dry strength, lb./sq. in. . .	10	12	15	20	22	25
<i>A.F.A. test-pieces, rammed 10 times.</i>						
Bulk density, g./c.c. . . .	1.90	1.91	1.92	1.93	1.94	1.95
Permeability No. . . .	38	37	36	35	34	33
Green strength, lb./sq. in. . .	8.7	7.5	5.6	4.0	2.8	1.9
Dry strength, lb./sq. in. . .	15	20	25	30	35	40

REFRACTORINESS.

A.F.A. test-pieces, rammed 10 times, were fired at 1550° C. for 2 hr. The test-pieces were faintly purple, slightly glazed, and contracted 5%.

TABLE LXVII.—*The Physical Characteristics of Avenuehead Rock Sand.*

MECHANICAL GRADING.			
Percentage Retained on B.S.I. Sieve No.—	As Received.	Sand Grade Only.	
5	0.3	0.2	
8	0.5	0.4	
10	0.4	0.1	
16	1.1	0.6	<i>By Elutriation :</i>
22	0.6	0.4	Medium sand
30	1.0	0.6	Fine sand
44	2.2	0.9	Silt
60	10.2	3.5	Clay
72	22.9	13.9	
100	39.6	52.3	
150	14.8	27.1	
Pass 150	6.4	...	
Total	100.0	100.0	100.0

TABLE LXVII.—*Continued.*

MOULDING CHARACTERISTICS.						
Moisture content, %	5.0	6.0	7.0	8.0	9.0	10.0
<i>A.F.A. test-pieces, rammed 3 times.</i>						
Bulk density, g./c.c.	1.72	1.74	1.76	1.78	1.80	1.82
Permeability No.	44	40	35	30	22	18
Green strength, lb./sq. in.	8.4	8.2	7.8	7.5	7.1	6.3
Dry strength, lb./sq. in.	135	170	210	250	290	325
<i>A.F.A. test-pieces, rammed 10 times.</i>						
Bulk density, g./c.c.	1.77	1.79	1.81	1.83	1.85	1.88
Permeability No.	24	20	17	15	11	10
Green strength, lb./sq. in.	15.0	14.3	13.6	12.8	11.9	10.6
Dry strength, lb./sq. in.	230	270	310	350	390	435

REFRACTORINESS.

A.F.A. test-pieces, rammed 10 times, were fired at 1550° C. for 2 hr. The test-pieces were white, glazed, and squatted.

TABLE LXVIII.—*The Physical Characteristics of Drumcavil Yellow Rock Sand.*

MECHANICAL GRADING.				
Percentage Retained on B.S.I. Sieve No.—	As Received.	Sand Grade Only.		
5	0.7	0.6	<i>By Elutriation :</i> Medium sand . . . 10.6 Fine sand . . . 65.0 Silt . . . 14.4 Clay . . . 10.0	
8	1.0	1.0		
10	0.8	0.4		
16	2.9	1.9		
22	2.0	1.6		
30	2.4	2.0		
44	4.1	2.0		
60	13.4	4.6		
72	19.8	13.5		
100	31.6	46.2		
150	14.9	26.2		
Pass 150	6.4	...		
Total	100.0	100.0		

MOULDING CHARACTERISTICS.						
Moisture content, %	5.0	6.0	7.0	8.0	9.0	10.0
<i>A.F.A. test-pieces, rammed 3 times.</i>						
Bulk density, g./c.c.	1.70	1.70	1.71	1.72	1.74	1.76
Permeability No.	30	29	27	25	24	24
Green strength, lb./sq. in.	13.0	12.0	10.8	10.7	10.3	10.2
Dry strength, lb./sq. in.	115	135	160	180	220	255
<i>A.F.A. test-pieces, rammed 10 times.</i>						
Bulk density, g./c.c.	1.76	1.77	1.78	1.80	1.81	1.83
Permeability No.	20	18	17	16	15	14
Green strength, lb./sq. in.	27.1	24.5	22.3	20.6	19.3	18.3
Dry strength, lb./sq. in.	215	245	280	325	370	420

REFRACTORINESS.

A.F.A. test-pieces, rammed 10 times, were fired at 1550° C. for 2 hr. The test-pieces fused completely.

TABLE LXIX.—*The Physical Characteristics of Drumcavil Grey Rock Sand.*

MECHANICAL GRADING.				
Percentage Retained on B.S.I. Sieve No.—	As Received.	Sand Grade Only.		
5	0.4	0.3	<i>By Elutriation :</i> Medium sand 10.4 Fine sand 68.1 Silt 10.5 Clay 11.0 100.0	
8	0.7	0.5		
10	0.5	0.5		
16	2.2	1.7		
22	1.6	1.3		
30	2.4	1.9		
44	3.3	2.4		
60	11.4	4.7		
72	19.8	16.7		
100	35.9	46.3		
150	15.2	23.7		
Pass 150	6.6	...		
Total	100.0	100.0		

MOULDING CHARACTERISTICS.						
Moisture content, %	5.0	6.0	7.0	8.0	9.0	10.0
<i>A.F.A. test-pieces, rammed 3 times.</i>						
Bulk density, g./c.c.	1.68	1.69	1.70	1.72	1.73	1.75
Permeability No.	31	30	28	27	26	25
Green strength, lb./sq. in.	9.2	9.5	9.0	8.5	8.2	8.0
Dry strength, lb./sq. in.	135	162	195	225	250	280
<i>A.F.A. test-pieces, rammed 10 times.</i>						
Bulk density, g./c.c.	1.73	1.74	1.76	1.78	1.80	1.82
Permeability No.	21	19	18	17	15	14
Green strength, lb./sq. in.	18.3	19.0	16.7	14.7	14.0	13.5
Dry strength, lb./sq. in.	210	255	300	345	390	430

REFRACTORINESS.
A.F.A. test-pieces, rammed 10 times, were fired at 1550° C. for 2 hr. The test-pieces fused completely.

V.—CONCLUSIONS.

The moulding characteristics of these Scottish rotten rocks are in accord with those of the Durham rotten rocks described in Part 9. The Carlops rock presents an extreme case of "rotting" and shows that, so far as the strength properties are concerned, such complete alteration is not desirable.

APPENDIX.—*Details of Localities.*

X1, Dullatur.

Situation.—Adjoining Dullatur Station on the Glasgow-Edinburgh (L.N.E.) railway line.

Petrology.—This is a friable, medium-grained sandstone, faintly banded in shades of brown. There are a few muscovite flakes on the bedding planes.

It is composed mainly of quartz grains and sericite. The quartz grains

are angular and some have frilled margins. Many of the grains contain linearly-arranged inclusions and exhibit strain shadows. There are a few flakes of pale-brown hydrobiotite. The sericite occurs as flakey aggregates which have fairly high polarization colours. Quartzitic aggregates are not extensively developed and most of the quartz grains are separated from the adjacent ones by sericite.

X2, Avenuehead.

Situation.— $1\frac{1}{2}$ miles from Glenboig Station on the north-eastern side of the Glenboig-Kirkintilloch railway line.

Petrology.—This is a pale grey, fine-grained friable sandstone containing traces of carbonaceous matter together with a few muscovite flakes on the bedding planes.

It is composed of quartz and secondary mica together with a few flakes of muscovite, bleached biotite, and chlorite. The majority of the quartz grains are free from linearly-arranged bubbles and from strain shadows. The quartz grains are angular and their margins are slightly frilled. The secondary mica is a sericite with rather lower polarization colours than usual; the sericite forms aggregates in which the pattern of the flakes is reminiscent of basket-work. Quartzitic aggregates are slightly developed.

X3, Drumcavil.

Situation.—1 mile north-west of Glenboig Station, close to the Glenboig-Kirkintilloch railway line.

Petrology.—A microsection of the milled material showed that it was composed of fine-grained, angular quartz sericite, together with a few flakes of muscovite. In the "grey" variety the sericite is very slightly stained with limonite, while in the "yellow" variety the staining is more pronounced. A few grains of microcline felspar are present in these sands.

X4, Carlops.

Situation.—Near to West Linton, 10 miles north-east of Peebles.

Petrology.—This is a white, medium-grained, extremely friable sandstone having a banded appearance due to variations in the proportions of quartz and clay minerals.

It is composed of quartz and kaolinite, together with a small proportion of sericite. The quartz grains are angular and have rather frilled margins. Many of the grains show strain shadows and contain linearly-arranged inclusions. The kaolinite forms typical vermicular aggregates, which contain a few wisps of sericite.

BRITISH BONDING CLAYS.*

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SYNOPSIS.

War conditions made necessary an investigation of the characteristics of indigenous bonding clays which might be suitable to replace, either partly or wholly, imported bonding clays. Typical examples of the three main groups of bonding clays have been examined, and the range of properties of synthetic moulding sands prepared with them is indicated. Experience has shown that, either alone or in admixture, these indigenous clays can be used successfully in many foundries.

I.—INTRODUCTION.

DURING the last twenty years there has been a rapid extension in the use of synthetic moulding sands, *i.e.*, mixtures made by milling together a high-silica sand and a clay; in some foundries, a small proportion of ferruginous, naturally bonded sand is also added to the mixture. In the United States, the use of synthetic sands became considerable between 1925 and 1930 and has increased steadily ever since; in Britain, the extensive use of synthetic sands is more recent and has been accentuated under war conditions. This is primarily due to synthetic moulding sands offering two main advantages over naturally bonded sands; their characteristics are more flexible, since the types of silica sand used as the base can be varied independently of the clay bond, and they facilitate the re-use of sand in mechanized foundries.

The western bentonites of Wyoming and the southern bentonites of Mississippi are largely used for synthetic-sand bonding in American foundries, but it is of interest to note that N. J. Dunbeck,[†] in considering present trends, calls attention to the possibilities of mixtures of the different types of clays, and indicates that selected plastic fireclays are widely used as bond clays in the United States.

When the use of synthetic sands developed on a considerable scale in Britain, attention was focused on the use of Wyoming bentonite, possibly because of the extremely plastic character it imparts to the sand mix, and to some extent as a result of this the importance of adjusting the composition of the synthetic sand so that it has hot strength sufficient to resist the wash of molten metal and to prevent casting distortion and yet insufficient to cause hot strains or tears, has not been appreciated fully. In this connection Dunbeck (*loc. cit.*) has shown how the hot-strength characteristics of moulding sands may be varied by the use of mixtures of different types of bonding clay.

The advent of the war introduced another factor into synthetic-sand practice in this country, namely, the necessity for reducing imports to the lowest possible level. As a result, attention has had to be directed

* Received September 19, 1945. This paper is published by authority of the Steel Castings Research Committee. The views expressed in it are the authors', and are not necessarily endorsed by the Committee as a body.

[†] *Proceedings of the Institute of British Foundrymen*, 1940-41, vol. 34, p. 17.

to home-produced bonding clays, and these have been used in many foundries. The home-produced clays should not be regarded merely as substitutes for Wyoming bentonite, as war-time experience has shown that they can be used successfully in many foundries, especially when they are considered as materials with their own special characteristics, and not just as substitutes.

In the past five years, the bonding characteristics of many home-produced clays have been examined, and details of typical ones are recorded below.

II.—TYPES OF BONDING CLAY.

Bonding clays may be classified in three groups according to their dominant clay-mineral constituent. These groups may be further subdivided according to the mode of origin, so giving the following classification :

- (i) Kaolinite clays, such as china clay, ball clay, and fireclay.
- (ii) Montmorillonite clays, such as fuller's earth and bentonite.
- (iii) Secondary mica clays, *i.e.*, clays rich in sericite or hydrobiotite.

The minerals associated with the dominant clay mineral may be other clay minerals, limonite, or minerals such as quartz, calcite, muscovite, feldspar, and siderite, whose bonding capacity is negligible. These associated minerals may modify the bonding characteristics of the clay considerably. Their nature depends on the mode of origin of the clay.

China Clay.—The principal china clay deposits at present being exploited occur in the Bodmin and St. Austell districts of Cornwall and along the southern edge of Dartmoor. In all the localities, granite intrusions have been decomposed by pneumatolysis.* In these granites, composed chiefly of quartz, orthoclase feldspar, and muscovite mica, the feldspar was hydrolysed to kaolinite, the granite being altered to a soft mass of quartz, muscovite, and kaolinite.

Crude china clay is essentially kaolinite with quartz and muscovite as impurities, separation being effected by a large-scale elutriation. The commercial china clays produced in this way usually contain some residual finely divided quartz and muscovite, and if the kaolinization of the feldspar is not complete, secondary micas may be present as intermediate breakdown products.

Ball Clays.—These are mainly worked in Dorset and Devonshire. Typical exposures show a series of flat-lying beds of sandy clay, sand, and various grades of ball clay, interspersed with thin seams of lignite. The sand and clay were carried by rivers from the china clay deposits of Devon and Cornwall, the separation of the kaolinite from the quartz and muscovite being effected during transport and deposition. The separated kaolinite now forms the ball clay deposits; where the separation was incomplete, beds of sandy clay accumulated.

Ball clays are generally more plastic than china clays, probably because their constituent kaolinite particles are smaller; mineralogically, ball clays are similar to commercial china clays, though they frequently contain some carbonaceous matter.

Fireclays.—These are the refractory underclays of coal seams and, as such, are worked in most of the British coalfields. Each of these underclays represents the ancient soil or subsoil below a swampy forest, which may be preserved as a coal seam. The underclay was formed from weathered rock debris transported by rivers and deposited in estuaries or lakes. Vegetation growing on this clayey material was responsible

* H. Dewey : " South-West England " (British Regional Geology). 1935, London : H.M.S.O.

for various changes in the constitution of its upper layers, the content of alkalies, lime, and magnesia being reduced either by solution by weak organic acids derived from the decaying vegetation in the swamp, or, particularly in the case of potash, by incorporation in the vegetation itself. During the leaching, secondary mica was replaced by kaolinite, whilst carbonaceous matter from rootlets remained in the clay.

Commercial fireclays are composed of kaolinite together with variable proportions of finely divided quartz, secondary quartz, and other accessory minerals. The more refractory clays are those richest in kaolinite.

Fuller's Earth.—The principal British deposits of fuller's earth occur at Combe Hay, near Bath, at Redhill, in Surrey, and at Woburn, in Bedfordshire. Each of the deposits is lenticular in form and apparently represents a school of volcanic ash which has decomposed, perhaps by the action of sea water, to form montmorillonite.

The clay mineral montmorillonite is characterized by the presence of exchangeable cations, such as calcium, sodium, potassium, and hydrogen. As they occur, the British fuller's earths are composed of calcium montmorillonite; Wyoming bentonite, on the other hand, is composed predominantly of sodium montmorillonite. The British fuller's earths, which are sold as bonding clays under the name of Fulbonds No. 1, 1A, and 1B, are selected natural fuller's earths carefully dried and powdered; in addition, fuller's earths which have been treated to convert the calcium montmorillonite to sodium montmorillonite are sold as Fulbonds No. 2, 3, 3A, and 4A. These commercial earths usually contain a small proportion of calcite and also a little feldspar.

Secondary Mica Clays.—This category, sometimes referred to as illite clays, includes most of the clay and shale beds of Britain which have not been subject to leaching by vegetation or to pneumatolysis. These clays are usually mixtures of the two secondary micas, sericite and hydrobiotite, together with finely divided quartz, muscovite, feldspar, and limonite; in some instances kaolinite is also present.

III.—THE BONDING CHARACTERISTICS OF TYPICAL CLAYS.

Fairly complete data have been obtained for the green and dry strengths of typical British bonding clays. The green-strength tests recorded here were made on A.F.A. test-pieces (2×2 in. cylinders) rammed ten times and prepared from mixes which had been milled sufficiently to develop the full bond strength. The green-sand test-pieces were crushed on a B.C.I.R.A. compression machine having a maximum load of 50 lb. The dry-sand test-pieces were prepared in the same way, dried at 200° C. for 2 hr. in an electric oven with air circulation, allowed to cool in tins with tight-fitting lids, and then crushed in an Olsen compression machine in which the load is applied through a screw and measured by a weight travelling on a beam.

Data for hot strength are not so complete, and at present it is only possible to point to the general hot-strength characteristics of each group of clays. The methods employed are the subject of a separate paper.* Cylindrical test-pieces, 2.256 in. high and 1.128 in. in dia., were used; they were placed in the compression machine with the furnace already at the required temperature and, in the tests recorded in Fig. 1, were crushed after soaking for 15 min.

The montmorillonite clays give a greater bond strength than the kaolinite and secondary mica clays, so two arbitrary standards were adopted for the proportion of bond added. With the montmorillonite clays (fuller's earths or Fulbonds), 5% of clay was added to the high-

* W. Davies and W. J. Rees: "The Hot-Strength Characteristics of Moulding Sands," *Journal of The Iron and Steel Institute*, 1945, No. II., pp. 61 P-70 P.

silica base sand; for all the other clays, a 7.5% addition was made. This difference does not affect the temperature at which the maximum hot strength is attained, but alters the magnitude of the hot strength. Chelford sand was used as the base sand in all the bonding tests.

(i) *The Bonding Properties of Typical China Clays.*

The green- and dry-strength-moisture curves for the following commercial china clays are recorded in Fig. 2:

Supreme Kaolin.—(St. Austell, Cornwall.) Composed almost entirely of kaolinite; the other constituents—small in amount—are quartz, muscovite, and sericite.

Speswhite Kaolin.—(St. Austell, Cornwall.) Similar to Supreme Kaolin, but contains a slightly higher proportion of quartz.

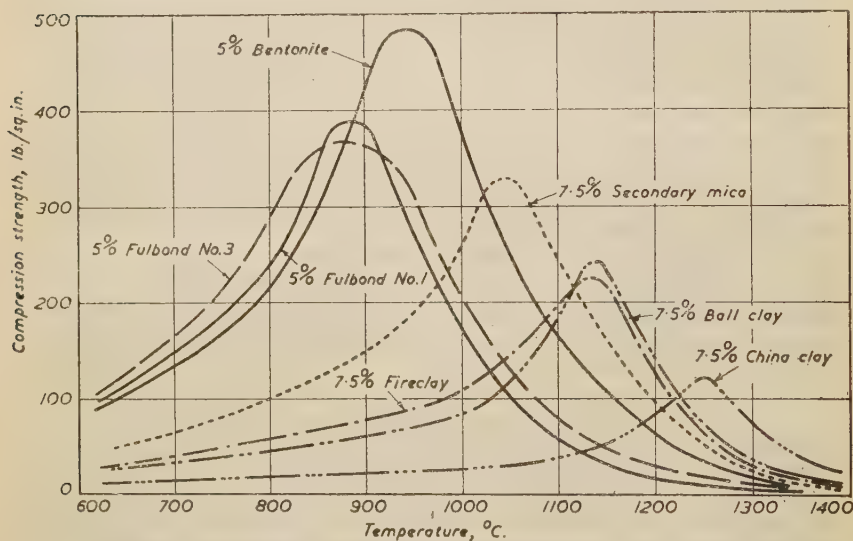


FIG. 1.—The Hot-Strength Characteristics of Chelford Sand with Typical British Bonding Clays. (Curve for 5% bentonite for comparison.)

K Plastic Kaolin.—(St. Austell, Cornwall.) Derived from an incompletely kaolinized granite. In consequence, it contains 10–20% of secondary mica (sericite) as well as kaolinite, quartz, and muscovite.

Bondil.—Similar to Supreme Kaolin.

White Rose China Clay.—Similar to K Plastic Kaolin, but contains more quartz.

Examination of Fig. 2 shows that Supreme Kaolin, Bondil, and Speswhite Kaolin give closely similar strength-moisture curves. The green strength is sensitive to moisture content and the dry strength is rather low. The green-strength-moisture curve for K Plastic Kaolin suggests that the presence of secondary mica in the clay makes its green strength less sensitive to moisture variations; the presence of secondary mica may also account for its better dry strength. The curves for the White Rose China Clay show the same trends as those for K Plastic Kaolin, but the actual strength values are lower; this may be attributed to the higher quartz content of this clay.

A general feature of synthetic sand mixes bonded with china clay only is their narrow plastic range, that is, the small range of moisture content between a mix which is too dry to mould and one which is too sticky to mould satisfactorily. The plastic range is wider for those clays

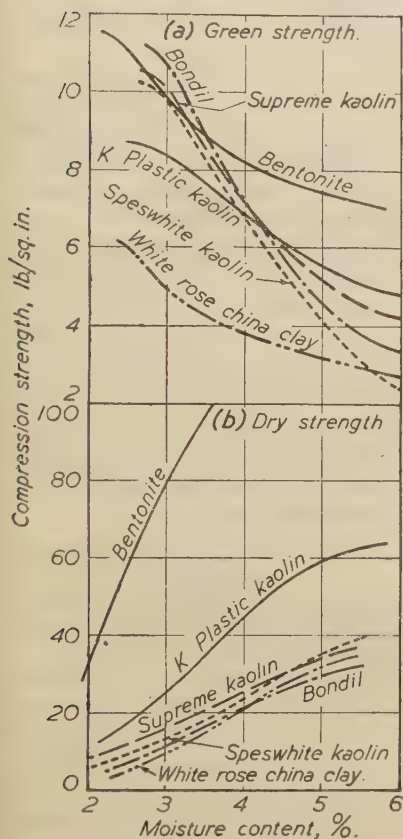


FIG. 2.—The Bonding Characteristics of Typical China Clays. Chelford sand bonded with 7.5% of china clay. (Curves for 5% bentonite for comparison.)

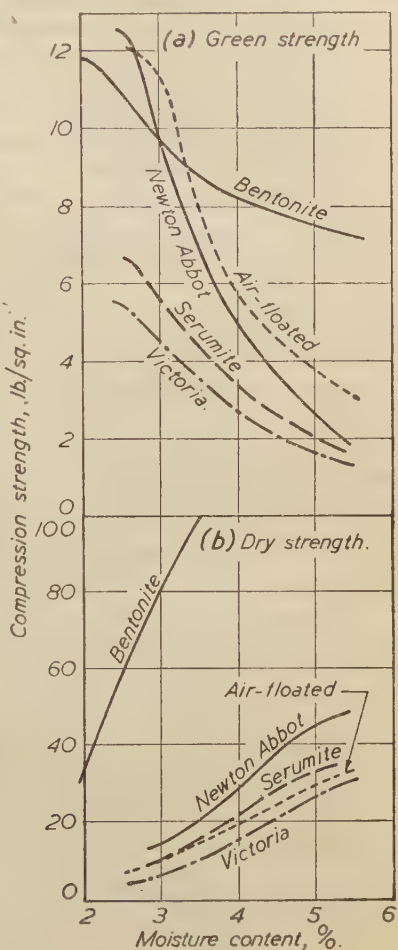


FIG. 3.—The Bonding Characteristics of Typical Ball Clays. Chelford sand bonded with 7.5% of ball clay. (Curves for 5% bentonite for comparison.)

which contain a noteworthy amount of secondary mica, e.g., K Plastic Kaolin. Dried test-pieces bonded with china clay tend to have friable surfaces. Although china clays have these disadvantages, they are extremely useful where hot strength must be retained for a considerable period at high temperatures.

(ii) *The Characteristics of Typical Ball Clays.*

The green- and dry-strength-moisture curves for the following commercial ball clays are given in Fig. 3:

Powdered Ball Clay.—(Newton Abbot, Devon.) Composed of kaolinite together with a small amount of quartz, muscovite, and felspar.

Air-Floated Ball Clay.—(St. Austell, Cornwall.) Similar to the powdered ball clay above.

Serumite.—(Bournemouth.) Composed of kaolinite and quartz, together with a small amount of sericite.

Powdered Ball Clay.—("Victoria," Parkstone, Dorset.) Similar to Serumite in composition.

Fig. 3 shows that the green strength given by the Newton Abbot and air-floated clays is rather more sensitive to moisture variations than is the case with the purer china clay such as Supreme Kaolin. The Serumite and Victoria clays give a lower green strength, possibly because they contain more quartz. The dry strengths of all four clays are of the same order as the china clays which contain little or no secondary mica.

Ball clays have hot-strength characteristics resembling those of china clays (see Fig. 1), though their peak strength is attained at a rather lower temperature. The plastic range of mixes bonded with ball clay is wider than that of china clays, but dried test-pieces still tend to have friable surfaces.

(iii) *The Characteristics of Typical Fireclays.*

The green- and dry-strength-moisture curves for the following fireclays are given in Fig. 4:

Bottle Clay.—(Woodville, Burton-on-Trent.) Composed of aggregates of kaolinite, stained with limonite, together with secondary mica and finely divided quartz.

Silklay.—(Woodville, Burton-on-Trent.) Similar to the bottle clay above, but contains rather more finely divided quartz.

Ground Fireclay.—(Wortley, Leeds.) Composed of kaolinite and quartz, together with a small proportion of sericite.

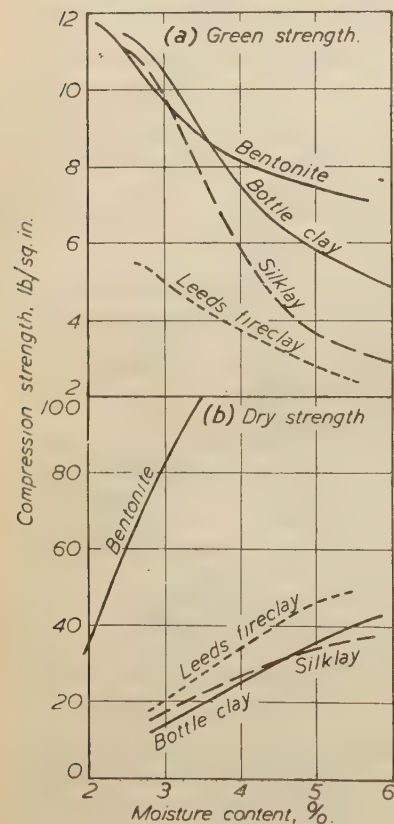


FIG. 4.—The Bonding Characteristics of Typical Fireclays. Chelford sand bonded with 7.5% of fireclay. (Curves for 5% bentonite for comparison.)

Fig. 4 shows that the green strengths of the bottle clay and Silklay are as sensitive to moisture variations as the pure china clays and that the dry strengths are rather low. Like china clays and ball clays,

fireclays give mixes with a rather narrow plastic range, and the dried test-pieces tend to have friable surfaces. The hot-strength characteristics of fireclays are similar to those of ball clays (*see* Fig. 1).

(iv) *The Characteristics of Fuller's Earths.*

At present, British fuller's earths are marketed in the following grades :

Fulbonds Nos. 1 and 1A.—Selected earths composed mainly of calcium montmorillonite.

Fulbond No. 1B.—A particularly pure earth composed almost wholly of calcium montmorillonite.

Fulbonds Nos. 2, 3, 3A, and 4A.—Selected earths treated to convert the calcium montmorillonite to sodium montmorillonite.

The green- and dry-strength-moisture curves for these Fulbonds are shown in Fig. 5. The green-strength curves for the untreated earths are steeper than those for the treated earths, and Fulbond No. 1B gives a considerably higher strength than the less pure Fulbonds Nos. 1 and 1A. All the Fulbonds give a good dry strength.

The hot-strength curves for treated and untreated Fulbonds are shown in Fig. 1. These clays give a higher hot strength than the kaolinite clays, but it is attained at a considerably lower temperature. At the temperature at which the kaolinite clays give their maximum hot strength, the hot strength given by the Fulbonds is extremely low. On the other hand, Fulbonds, particularly the treated grades, have a much wider plastic range than the kaolinite clays, and the dried test-pieces have much firmer surfaces. Green sand moulds prepared with Fulbond, particularly the treated grades, do not dry off so much on standing as kaolinite-bonded moulds.

(v) *The Characteristics of Secondary Mica Clays.*

The green- and dry-strength-moisture curves for clays rich in secondary mica are shown in Fig. 6.

Kingbond.—Composed of sericite, together with a small proportion of kaolinite, quartz, and carbonaceous matter. The sericite is stained with limonite.

"Flour Substitute."—A clay composed almost wholly of sericite, the only other constituent being quartz.

Colbond.—Composed of very finely divided secondary mica, some of which is slightly pleochroic in shades of brown.

Kloider.—Composed of sericite together with a small proportion of quartz and kaolinite. The sericite is slightly stained with limonite.

Distribond 3.—Composed mainly of finely divided secondary mica and quartz.

Fulbond K.—A natural mixture of secondary mica and kaolinite, together with a small proportion of quartz; it is obtained from a deposit in Kent.

Clay from Stormy Quarry, S. Wales.—Composed mainly of sericite and quartz.

Clay from Blanchland.—Composed mainly of hydrobiotite and quartz.

Fig. 6 shows that these clays have characteristics intermediate between those of the kaolinite and montmorillonite clays. This is also true of their plastic range. They attain their maximum hot strength at a rather higher temperature than the montmorillonite clays, as will be seen from Fig. 1. Some of these secondary mica clays, notably Fulbond K, are much more refractory than the montmorillonite-bearing Fulbonds.

IV.—THE REFRACTORINESS OF BONDING CLAYS.

The refractoriness, by cone test, of various samples of western bentonite tested is in the range $1290-1350^{\circ}\text{C}$. That of Fulbonds Nos. 1 to 4A inclusive is in the range $1120-1220^{\circ}\text{C}$., and that of Fulbond K, $1320-1360^{\circ}\text{C}$.

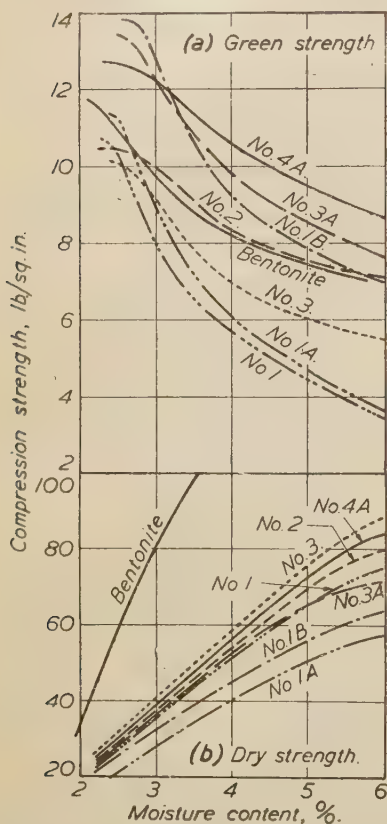


FIG. 5.—The Bonding Characteristics of Fulbonds from Redhill and Bath. Chelford sand bonded with 5.0% of Fulbonds. (Curves for 5% bentonite for comparison.)

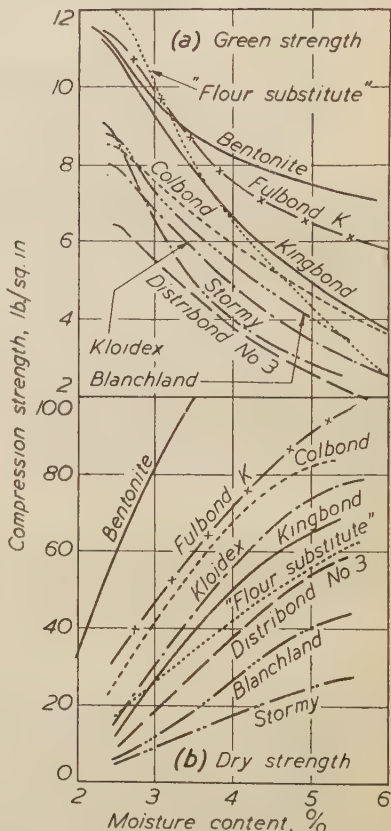


FIG. 6.—The Bonding Characteristics of Typical Secondary Mica Clays. Chelford sand bonded with 7.5% of clay. (Curves for 5% bentonite for comparison.)

The ball clays tested are in the range $1580-1670^{\circ}\text{C}$.; and the fireclays, $1630-1690^{\circ}\text{C}$. The secondary mica clays examined, other than Fulbond K, are within the range $1300-1500^{\circ}\text{C}$.

V.—CLAY MIXTURES.

At present there is little information available concerning clay mixtures based solely on British bonding clays. The green- and dry-strength-moisture curves for a mixture of 90% Bonnybridge fireclay with

10% Fulbond No. 1 are shown in Fig. 7. This mixture is reported to have been used in a steel foundry with satisfactory results. Some trials have also been made with mixtures of Wyoming bentonite with British bonding clays. The green- and dry-strength-moisture curves for two mixtures are shown in Fig. 7.

Laboratory tests indicate that certain clays, such as Fulbond K, Colbond, Kloidx, and Kingbond, can act as "extenders" of bentonite, probably because their structures are similar, and any slight loss in green strength and dry strength can be compensated by a small increase in the proportion of the mixed clay bond. Such properties as plasticity and surface strength (when green sand moulds are left for some time before pouring) are of the same order as with bentonite alone. Promising foundry trials have been made with mixtures of bentonite and Fulbond No. 1 and bentonite and Kingbond, and although the trials were discontinued the results were such as to merit further investigation.

Other laboratory work on mixtures of clays includes series of tests on specially milled mixtures of bentonite with kaolins and of Fulbond No. 1 with kaolins. Two mixtures of particular promise are those of bentonite with K Plastic Kaolin and of Fulbond with K Plastic Kaolin, the general behaviour of these mixtures being comparable with that of the montmorillonite clay alone.

VI.—CONCLUSIONS.

Bonding clays are available, from British deposits, having a wide range of bonding characteristics. For some types of founding, though no single clay may have the most suitable bonding characteristics for a particular sand system, the possibility of producing a suitable combination of plasticity and green, dry, and hot strength by the use of mixtures of clays, is envisaged.

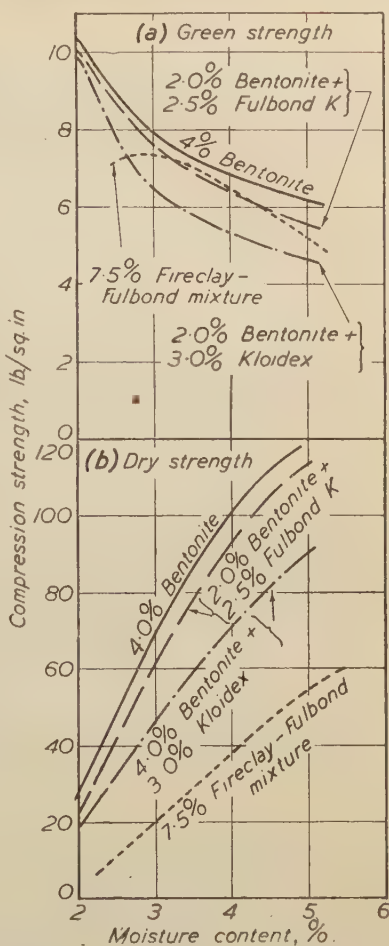


FIG. 7.—The Bonding Characteristics of Some Clay Mixtures. Chelford sand with mixtures indicated.

A PRELIMINARY INVESTIGATION OF THE CONSTITUTION OF MILD-STEEL ARC-WELD DEPOSITS.*

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(Figs. 3 to 23 = Plates XI. to XIV.)

SYNOPSIS.

The oxygen, hydrogen and nitrogen contents of mild-steel weld deposits laid down under certain standard conditions, and also the form in which the oxygen is present, have been determined. Deposits from six different electrodes were found to differ appreciably in their contents of the gaseous elements. Observations connecting these differences with the compositions of the electrode coatings have been made.

A knowledge of the distribution of the oxygen, coupled with chemical analysis, has made it possible to determine the amounts of silicon and manganese present in elemental form in weld metal. The oxide inclusions have been identified by X-ray examination.

The total hydrogen content of weld metal is divisible into two parts, one of which escapes from the metal at room temperatures whilst the other is held more or less permanently. The total hydrogen is approximately proportional to the total available hydrogen in the electrode coating, but the partition of the gas between the two forms is not constant for a given electrode and is apparently influenced by factors which are not yet understood.

The effect of heat-treatment on the microstructure and on the precipitation of the nitride-bearing constituent has been studied, but no attempt has been made to correlate the constitution of weld metal with its mechanical or other properties.

The form of combination of sulphur—as manganese sulphide—has been established by X-ray examination, and some suggestions in connection with the apparently anomalous sulphur prints given by arc-weld metal are put forward.

INTRODUCTION.

THE very considerable expansion which has taken place during the past few years in the use of arc-welding methods for the construction of a large variety of steel structures has led to an increased interest in a knowledge of the fundamentals of the metallurgy of steel weld metal. At the beginning of 1943, the Advisory Service on Welding, Ministry of Supply, invited the co-operation of the National Physical Laboratory in building up the scientific background of ferrous arc-welding by an investigation of certain problems which are stated below:

(1) One of the chief troubles encountered in arc-welded joints is the formation of cracks either in the weld deposit itself or in the heat-affected zone of the parent metal. The rôle which hydrogen plays in causing, or assisting in, the formation of the different types of crack is still a matter of uncertainty, and although many suggestions have been put forward as to the way in which the gas behaves in this connection, the necessary preliminary systematic investigation of the amount and form of the hydrogen actually present in weld metal has not previously been undertaken. The National Physical Laboratory was accordingly requested to carry out an

* Received February 20, 1945.

investigation into the hydrogen content of weld metal; to ascertain its origin, and thus to make possible a control of the conditions, as far as hydrogen is concerned, under which weld metal is deposited.

(2) The form in which elements such as manganese and silicon exist in weld metal will affect many of the properties of the material. Ordinary chemical analysis gives relatively little information on this point, but new methods, such as the alcoholic iodine method developed at the National Physical Laboratory, coupled with X-ray analysis of the residue, are now available for the determination of the inclusions and have been found to be extraordinarily useful for application to this type of problem.

(3) The relative effects on the hardness of weld metal of carbon and nitrogen are not completely understood. Before undertaking a specific investigation on this point, it was hoped that useful information might be obtained in the course of the work visualized under (1) and (2) above, which would indicate possibilities for future lines of research on this problem.

So far, only a preliminary survey of the problems has been possible and a wide field of research awaits investigation, but this paper is presented at the present juncture because some interesting results have already been obtained. Experiments carried out both at the National Physical Laboratory and elsewhere had already shown that weld metal usually contains significant quantities of hydrogen. None of these experiments, however, constituted a systematic study of the problem under controlled conditions, and the field was, therefore, essentially unexplored. Except under unfavourable (humid) conditions of laying down arc-weld deposits in air, the atmosphere itself cannot be regarded as a major source of any hydrogen which may enter the metal during deposition. A small amount of hydrogen may be present in the electrode core wire or in the parent plate, but by far the most important source is the flux coating with which the electrode wire is usually covered. The coatings can, in spite of considerable differences in composition, be classified into two groups, according as to whether or not they contain an organic compound of the cellulose type—alpha flock, cotton braid, &c.—in addition to the fluxing mineral matter. Owing to the necessity for obtaining a high degree of adherence of the coating to the core wire, a binder—usually an alkaline silicate—is also universally employed.¹ After the coating has been applied to the wire the electrodes are dried at a relatively low temperature.

The two main groups of electrode coatings may be further subdivided according to the composition of the mineral matter they contain. This classification is not sharply defined, as considerable overlapping is found. Two main subdivisions may, however, be recognized, namely those in which the mineral matter contains a large percentage of iron oxide and those in which titanium oxide preponderates. In addition to these main constituents there are normally varying amounts of silica, alkaline silicates of the felspar type, alkaline earth carbonates and ferro-alloys such as ferro-manganese and ferro-silicon. Some commercial electrode coatings also contain an alkaline earth fluoride, usually calcium fluoride, which may replace some of the other constituents.

TYPES OF ELECTRODE USED IN THE INVESTIGATION.

It was decided to examine a small group of standard commercial mild-steel electrodes having as wide a range of flux-coating compositions as possible and to adopt one single type of weld on mild-steel plate. Five commercial electrodes were selected, together with one developed by Mr. G. L. Hopkin of the Armament Research Department, Ministry of Supply, designed to have a coating especially low in hydrogen. Electrodes having coatings containing fluorides were omitted in view of the inter-

ference of these compounds in the moisture determinations and possibly in the estimation of non-metallic inclusions by the alcoholic iodine method.

TABLE I.—*Details of Electrode Coatings.*

	Electrode A.	Electrode B.	Electrode C.	Electrode D.	Electrode E.	Electrode F.*
Mineral matter.	Iron oxide. Silica. 90% Fe-Mn. Felspar or other silicates.	Iron oxide. Silica. 90% Fe-Mn. Felspar or other silicates.	Rutile (TiO ₂). CaCO ₃ . 90% Fe-Mn. Felspar or other silicates.	Rutile (TiO ₂). CaCO ₃ . 90% Fe-Mn. Felspar or other silicates.	Ilmenite (60% TiO ₂ , 40% FeO). Manganese di- oxide. Felspar or other silicates.	Rutile (TiO ₂) 55.8% Dolomite 19.2% 90% Fe- Mn 15.4% Orthoclase 9.6%
Organic matter, string or yarn.	Alpha flock.	...	...	Asbestos yarn supported on fine metal wire.	Cotton braid.	...
Binder.	Alkaline silicates—sodium silicate or a mixture of potassium silicate.					2Na ₂ O.7SiO ₂ (sp. gr. 1.4). 27 parts by wt.
Method of appli- cation of coat- ing.	Extruded as paste.	Dipped, i.e., ap- plied as a sus- pension.	Extruded as paste.	Extruded as paste.	Extruded as paste.	Extruded as paste.

* Electrode F was developed by Mr. G. L. Hopkin, Armament Research Department, Ministry of Supply, to whom the authors are indebted for details of the composition. The electrode is known as R.D.1 Standard Electrode.

In Table I. are shown the general characteristics of the coatings of the six types of electrode used in the investigation. All have mild-steel core wires (for analyses *see* Table IX.).

The electrodes selected cover the main sub-divisions referred to above. *A* and *B* are similar as regards mineral matter (iron oxide-silica type), but *A* has an admixture of organic matter. *C*, *D*, and *F* are of the titanium oxide type, but *D* has asbestos yarn. *E* is also of the titanium oxide type, but differs in having manganese dioxide and cotton braid in the coating. In addition, in this coating ilmenite is used instead of rutile.

At a later date it was decided to include in the investigation, for comparison, a less extensive examination of weld deposits laid down by two automatic processes. In one of these a bare mild-steel electrode (copper-plated to reduce oxidation) together with a powdered anhydrous flux, consisting essentially of calcium silicate, is employed. In the other, a covered electrode (fluoride-type coating) is used. To avoid confusion, it will be convenient to consider the results obtained on these deposits separately.

DETERMINATION OF THE HYDROGEN PRESENT DURING DEPOSITION OF WELD METAL.

As indicated above, the most probable source of the hydrogen present in weld metal is that combined in various forms in the electrode coating : moisture remaining after the makers' drying process, hydrogen in the organic matter (where present), and water combined with the mineral matter or binder. It is to be expected that, whereas water derived from the first two sources will be released at relatively low temperatures—probably below 600° C.—that combined with the mineral matter or binder will be completely evolved only at higher temperatures, possibly not until the fusion point of the coating is reached.

During the actual welding operation, the whole length of the electrode is raised considerably above room temperature. Opportunity is thus available for drying and combustion of organic matter to occur at a distance along the electrode from the weld. It seemed reasonable, therefore, to suppose that the amount of combined water in the coating might exert more influence on the quantity of hydrogen entering the weld deposit than that produced—possibly in greater quantity—by the drying of the coating and the combustion of its organic constituents. The object of the investigation outlined under (1) above may thus be more specifically stated as follows : To determine the hydrogen content of mild-steel weld metal deposited under standard conditions using the standard electrodes listed in Table I., and, if possible, to correlate the results with the amount of hydrogen present in one form or another during the deposition of the metal. This hydrogen includes that in the parent plate and in the core wire, in addition to the potential hydrogen present in one or all of the forms indicated above in the flux coating of the electrode.

Sizes of Electrode Core Wires and Parent Plate.

It was hoped at the commencement of the investigation to examine each type of electrode in selected core-wire sizes between 12 and 4 S.W.G. This has, however, not so far been possible and the actual sizes employed are listed below :

Electrode <i>A</i>	.	.	.	6 S.W.G.
„ <i>B</i>	.	.	.	12 and 8 S.W.G.
„ <i>C</i>	.	.	.	12 S.W.G.
„ <i>D</i>	.	.	.	12 S.W.G.
„ <i>E</i>	.	.	.	12 S.W.G.
„ <i>F</i>	.	.	.	6 S.W.G.

A sufficiently large piece of a 1-in. mild-steel plate for the investigation was provided through the courtesy of the Advisory Service on Welding, Ministry of Supply.

Hydrogen Contents of the Electrode Core Wires and Plate.

The hydrogen contents of the plate and of representative samples of each electrode core wire were determined by the vacuum-fusion method.² The results are given in Table IX. and are very low.

Standardized Treatment of the Electrodes.

Since each make and size of electrode was obtained in one large batch, it was assumed that the composition and potential hydrogen content of each coating would be consistent. In order, however, to standardize, as far as possible, the moisture content of the coatings, the electrodes were baked at 50° C. for 2 hr. in an air oven before use. This temperature was chosen so as not to affect the organic constituents of the coating, when present.

Determination of the Ratio of Weight of Core Wire to Coating.

After the above standardizing treatment, the weight of coating per 100 g. of core wire for each electrode was determined and is shown in Table III. The coatings after stripping were broken into small pieces and used in the determinations of moisture content; fine grinding of the coatings was not considered desirable owing to the possibility of gain or loss of moisture.

Moisture Determinations on the Coatings.

In order to distinguish moisture determined by the usual "combustion of organic material" method at about 600° C.—which will include moisture retained after the makers' "stoving" process as well as water formed by the oxidation of organic matter—from water combined with the mineral matter, it was proposed to make determinations at a series of temperatures commencing at 600° C. and going, if possible, up to the fusion point of each coating.

These determinations were carried out in a quartz tube, 24 in. long and 1 in. in dia., closed at one end. The open end was fitted with a glass cap carrying a quartz delivery tube which projected inside the main tube to the closed end. The delivery tube was connected to a P_2O_5 drying tube, a bubbler containing concentrated sulphuric acid, and a cylinder of oxygen. An exit tube from the glass cap was connected to a P_2O_5 drying tube and a bubbler containing concentrated sulphuric acid. One g. of the sample of coating was weighed into a silica or fireclay boat and the boat placed inside the quartz tube near to the closed end. The tube was heated in a carborundum-type electric resistance furnace.

In order to ensure complete combustion of organic matter, it was found necessary to commence the heating with the closed end of the furnace tube projecting beyond the far end of the furnace. When a temperature of 600° C. was reached, the tube was gradually drawn within the hot zone of the furnace, dry oxygen being passed over the sample continuously. Heating was continued for 2 hr. after the sample had entered the hot zone. The tube was then withdrawn from the furnace and allowed to cool to room temperature. The P_2O_5 weighing tube was weighed before and after the experiment. A similar procedure was adopted at the higher temperatures, the furnace tube being drawn in when the temperature had reached 600° C. and the desired working temperature attained as rapidly as possible. The "blank" for the apparatus even at the highest temperature employed was negligible.

With coatings which included string or yarn, a proportionate amount was included in the sample for the determination.

With every coating, incipient fusion commenced at about 1200° C. and a fluid fusion was obtained at about 1300° C. A temperature of 1200° C. was sufficient to ensure a total yield of moisture. It was, moreover, found that the difference between the moisture as determined at 600° and at 1200° C. was small, and it was decided not to employ intermediate temperatures. The main work was, therefore, carried out using temperatures of 600° and 1200° C. only. The results of individual determinations are given in Table II.

TABLE II.—*Moisture Content of Coatings Expressed in Weight Per Cent.*

Electrode.	Moisture at 600° C. Weight-%.			Moisture at 1200° C. Weight-%.			Difference between Mean Values. %.
	Deter- mination (a).	Deter- mination (b).	Mean. %.	Deter- mination (a).	Deter- mination (b).	Mean. %.	
A 6 S.W.G. .	8.41	8.52	8.45	9.37	9.00	9.18	0.73
B { 12 S.W.G. .	2.00	2.08	2.04	2.18	2.26	2.22	0.18
{ 8 S.W.G. .	2.05	...	2.05	2.21	...	2.21	0.16
C 12 S.W.G. .	3.79	3.57	3.68	4.16	4.22	4.19	0.51
D 12 S.W.G. .	5.04	4.97	5.00	5.69	5.72	5.70	0.70
E 12 S.W.G. .	{ 13.02*	13.29*	12.48	11.92	11.51	11.20	} †
	11.44	12.16		10.40	10.99		
F 6 S.W.G. .	1.32% at 150° C.; 2.08% at 820° C.						

* Sample mixed with copper oxide.

† Probably very small.

Difficulty was experienced with the coating of electrode *E*, probably because of the high proportion of cotton braid (57% approximately by weight). A portion of the mineral matter tended to adhere closely to the braid and was difficult to detach. It was, therefore, not easy to ensure that the analytical samples contained the correct proportions of mineral matter and braid. This is shown by the scatter of the results for this coating in Table II.

With a high proportion of organic matter, as in this coating, it seemed desirable to assist the action of oxygen in producing complete combustion by mixing the sample with copper oxide. This was tried for two samples (600° C.) and appeared to lead to higher and more consistent results. Copper oxide could not be used at the higher temperature (1200° C.), so alumina was tried but led to the fracture of the quartz furnace tube. The results shown in Table II. for a temperature of 1200° C. were, therefore, obtained by the normal procedure as indicated above.

The measurements of the moisture content of the coating of electrode *F* were carried out by G. L. Hopkin, who, as indicated earlier, was responsible for introducing this experimental coating. Electrode *F* was not available when the moisture determinations were being carried out at the National Physical Laboratory and it was decided that it was not necessary to determine its moisture content at 600° and 1200° C.

In Table III. are summarized the results of the moisture determinations together with the weight of coating per 100 g. of core wire and the potential hydrogen (calculated from the moisture determinations) per 100 g. of wire.

In calculating the potential hydrogen, the total water content (as determined at the highest temperature employed) of each coating has

TABLE III.—*Potential Hydrogen in Electrode Coatings.*

Electrode.	Wt. of Coating per 100 g. of Wire, g.	Wt. of Water in Coating at 1200° C. %.	Wt. of Water per 100 g. of Wire, g.	Potential Hydrogen per 100 g. of Wire, ml.
A 6 S.W.G. .	26.5	9.2	2.4	3000
B { 12 S.W.G. .	46.6	2.2	1.0	1300
8 S.W.G. .	42.3	2.2	0.85	1150
C 12 S.W.G. .	40.8	4.2	1.7	2100
D 12 S.W.G. .	31.4	5.7	1.8	2200
E 12 S.W.G. .	31.9	11.2	3.6	4400
F 6 S.W.G. .	32.5	2.1 (at 820° C.)	0.7	850

been used. If the suggestion that the water combined with the mineral matter is the significant factor in controlling the amount of hydrogen which enters the weld deposit, were correct, then it would have been more accurate to consider as a source of potential hydrogen only that portion of the water which is evolved above 600° C. From the work which has been carried out to date, it appears, however, that this theory is not borne out in practice. The hydrogen found in a weld is approximately proportional to the total water content of the coating rather than to either of what may be termed the "low-temperature water" or the "high-temperature water."

A comparison between the results in Tables III. and IX. shows that the hydrogen contents of the plate and core wires are insignificant as compared with those of the coatings.

DETERMINATION OF THE HYDROGEN IN WELD METAL.

Type and Size of Weld.

One standard type and size of weld was used throughout. The channel rather than the fillet type was selected and, in order to provide sufficient weld metal at the base of the channel for subsequent examination, a U-section was chosen, the form of which was as follows. The base on which the weld metal was deposited, consisted of a piece of the standard mild-steel plate, 6 in. long, 1 in. wide, and $\frac{1}{2}$ in. thick. Two pieces of copper plate, each 6 in. long, $1\frac{1}{2}$ in. high, and $\frac{1}{2}$ in. thick, were clamped one on each side of the steel plate. This provided a channel of rectangular section, 6 in. long, 1 in. wide, and 1 in. deep, of which the base was steel and the sides copper, the ends being open. This channel was filled with weld metal, the copper sides, to which the deposit did not adhere, were removed, and the remaining composite, consisting of a weld deposit ($6 \times 1 \times 1$ in.) attached to the steel base, was ready for subsequent operations. The weight of such a deposit was about 600 g.

Method of Welding.

Welding was carried out, using A.C. arc-welding equipment, with the channel supported so that it sloped longitudinally at about 30° to the horizontal. The deposit was laid down across the full width of the steel base, working upwards from the lowest point. When one complete run had been deposited, the whole mass was severely quenched in water, and, after the slag had been removed, was replaced on the support, but reversed longitudinally so that the second run was laid down in the opposite direction from the first. The quenching, removal of slag, and reversal were carried out after every run until the channel was completely filled.

The average current during the welding operation was noted for each make and size of electrode.

The conditions of welding were designed to retain as much hydrogen as possible by severe quenching after each run. It is possible that, in a multi-run deposit of the type employed, hydrogen may be lost from earlier runs during the deposition of later ones. This point will be considered later. From the extreme conditions employed in the present investigation, it is possible to postulate others, less drastic in nature, until natural air cooling between individual runs is reached, and it may be desirable that the work should be repeated using another set of conditions more closely related to those obtaining in practice. It must be borne in mind, however, that the type of weld itself would not be used industrially, particularly with 12 S.W.G. core wires, and was chosen solely with a view of obtaining a large mass of weld deposit at the base of the channel so that a comparison could be made of the effect on such constituents as oxygen and nitrogen of weld metal laid down well screened from air (at the base of the deep channel) and similar metal not so screened (at the top of the channel).

Extraction of Hydrogen at Room Temperature.

Preliminary experiments confirmed the view that hydrogen may begin to be evolved from mild-steel weld metal at room temperature immediately after deposition. It was thus necessary to place the weld in a closed vessel as soon after completion as possible, so that as gas was evolved it could be collected and analysed. Immediately, therefore, the final run had been deposited and the quenching and removal of slag carried out, the copper walls were removed and the weld, with its attached steel base, placed in a closed chamber. The final quenching was carried down to a temperature of about 100° C., so that when the metal was removed from the bath, it continued to steam during the process of slag removal, drying off practically all the adhering water.

The apparatus employed for these experiments is as follows : The closed chamber consists of a rectangular-section steel vessel ($6\frac{1}{4} \times 1\frac{1}{4} \times 1\frac{3}{4}$ in.) into which the weld with its steel base fits snugly leaving only a small dead space (about 100 c.c.). One end of the vessel is permanently closed, while to the other is welded a large flange. A similar flange, with a short length of small-bore steel tube attached, forms the lid of the vessel, the two flanges being lapped optically flat to produce a vacuum-tight joint. (A small quantity of vacuum grease is used as a lubricant.) The steel tube leading from the lid of the vessel is connected through a glass tap to a system consisting of a Toepler pump (having its own isolating tap), a McLeod vacuum gauge, a small drying tube containing P_2O_5 , and a side tube leading, *via* a second glass tap, to a large vessel (5 litre capacity) and a rotary oil-vacuum pump. The purpose of the P_2O_5 is to adsorb any residual water remaining on the surface of the weld and is essential in order to permit pressure readings to be taken on the McLeod gauge. The volume between the Toepler pump and the vessel containing the weld is kept as small as possible. The whole system is arranged to be vacuum tight and kept permanently assembled, except for the vessel holding the sample, which is detached as required at the flanged joint.

The method of operation is as follows : The whole system up to the tap connecting with the sample vessel is evacuated down to a pressure of about 0.01 mm. of mercury and the Toepler pump is then isolated. As soon as a weld sample is ready (*i.e.*, within 5 min. of the completion of the last run), it is placed in the sample vessel and the joint to the lid made. The tap attached to the lid is then opened and the gas (air) in the dead space around the weld allowed to expand into the large reservoir for a

period of about 4-5 sec., after which the tap to the reservoir is closed, the pressure of the gas in the sample chamber having been reduced to about 15 mm. of mercury (*i.e.*, its volume is reduced from about 100 to 2 ml. at N.T.P.). The tap to the Toepler pump is now opened and the pump operated down to a pressure of about 0.01 mm. of mercury, the gas being collected in a suitable tube ready for analysis. As gas is evolved from the weld, it is removed from the system by means of the Toepler pump, the pressure being kept as low as possible (it unavoidably builds up overnight). At the commencement of each experiment, the gas collected during each 24-hr. period is measured and analysed. In the later stages, however, insufficient gas is evolved in 24 hr., and measurements and analyses are carried out at longer intervals.

During the first few days, the rate of evolution is relatively high, but it gradually falls until, after a period which may extend to 60 days or more, it has become almost zero. The experiments were in every case terminated when the rate of evolution had dropped to 0.01 ml. per 100 g. of weld per day, and the weld was then removed from the sample chamber for the machining necessary for the next stage in the investigation.

Except for the gas collected at the start of an experiment, which is essentially residual air, analysis showed that over the whole course of a determination, hydrogen only is evolved from weld metal in the cold.

It will be noted from the above description of the operation of the experiment, that once the tap leading to the reservoir has been closed, all gas within the sample vessel is collected and analysed. A doubt arose, however, as to whether, by allowing the major portion of the original air round the sample to escape to waste into the reservoir, a certain amount of hydrogen had not already been evolved and was not also being lost. The reason for the adoption of the procedure as described, was that owing to irregularities in the top surface of the weld, it was not possible to design a vessel which would give a dead space appreciably less than the 100 c.c. indicated. If, therefore, all the gas in this space (100 ml. at N.T.P.) were collected by means of the Toepler pump, the initial analysis in each experiment would be difficult and tedious, since it would involve the determination of a small quantity of hydrogen in a very large volume of air. This latter procedure was, however, adopted in some of the preliminary experiments and it was found that within the limits of experimental accuracy, no hydrogen is lost during the 4-5 sec. while the original air contained in the sample vessel is disposed of by expansion into the reservoir.

In Table IV. the results for typical welds made with the various electrodes are given; the hydrogen which represents that amount which is extracted *in vacuo* at room temperature is expressed as ml. at N.T.P. per 100 g. of weld metal.

TABLE IV.—*Hydrogen Extracted from Welds at Room Temperature.*

Electrode.		Hydrogen Extracted at Room Temperature, ml. per 100 g. of weld.	Rate of Hydrogen Evolution at Termination of Experiment ml. per 100 g. of weld per day.	Duration of Experiment, days.
A	6 S.W.G.	5.4	0.01	70
B	12 S.W.G.	1.2	0.01	24
	8 S.W.G.	2.3	0.01	42
C	12 S.W.G.	1.4	0.01	27
D	12 S.W.G.	2.8	0.01	36
E	12 S.W.G.	2.0	0.01	58
F	6 S.W.G.	3.2	0.01	70

The form of the evolution curve is similar in every case examined, and four such curves are shown in Fig. 1.

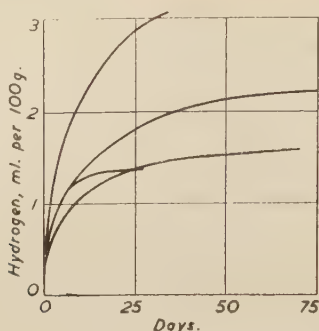


FIG. 1.—Hydrogen Evolved at Room Temperature.

Machining the Weld.

Before the next stages of the investigation could be undertaken, it was necessary to cut the weld deposit in various ways. Since preliminary experiments had shown that, after the termination of the cold extraction, there still remained within the deposits significant amounts of residual hydrogen, it was proposed to determine these, together with the total oxygen and nitrogen, by the vacuum-fusion method.² In this connection it was important to know whether the exposure of new surfaces by machining would lead to an increase in the rate of hydrogen evolution at room temperature, and thus result in the loss of an indeterminate part of the residual hydrogen during the preparation of the specimens for vacuum-fusion analysis.

The actual machining operations are as follows: First the weld metal is separated from the base plate by a longitudinal cut parallel to the upper surface of the base plate and about $\frac{1}{8}$ in. inside the deposit itself. Then about 1 in. is removed from each end of the deposit to eliminate end effects and finally, by another longitudinal cut, parallel to the first, the metal is divided into two approximately equal portions—an upper and a lower. A specimen for vacuum-fusion analysis is then machined from each end of each portion of the weld—the two specimens from the upper portion being taken from as near the top surface as possible, while those from the lower portion are taken very close to the base. These operations take in all about 2–3 hr., after which the specimens are weighed, inserted in the previously assembled vacuum-fusion apparatus and the determinations of oxygen, nitrogen, and hydrogen commenced at once.

It will be seen from Table IV. that the rate of evolution of hydrogen at the end of the cold extraction was about 0.01 ml. per day per 100 g. of metal. If the exposure of fresh surfaces produced no effect, then after the machining operations, the evolution should continue at the same—negligible—rate as before. Accordingly, on several occasions, a weld sample was brought to the stage when normally the cold-extraction experiment would be terminated and the vacuum-fusion analysis commenced. Instead, however, after the machining operations outlined above had been carried out, all the pieces were immediately returned to the cold-extraction apparatus. The new rate of evolution was followed over the course of several days and in every case it was found, after allowing for the loss in weight during machining, that the rate continued just as it would have

done had the metal not been removed and machined. It was assumed, therefore, that only a negligible loss of hydrogen would be incurred by the procedure adopted in preparing vacuum-fusion specimens.

Vacuum-Fusion Analyses of Weld Samples.

The total oxygen, nitrogen, and hydrogen (residual) contents of the specimens taken from the four positions within each weld deposit indicated above, were determined by the vacuum-fusion method and the results are recorded in Table V. It should be noted that these results were obtained on the same individual samples as were used in determining the hydrogen extracted at room temperature and given in Table IV.

TABLE V. —Oxygen, Nitrogen, and Hydrogen (Residual) by Vacuum Fusion.

Electrode.	Position within Weld Sample.	Oxygen. Wt.-%.	Nitrogen. Wt.-%.	Hydrogen (Residual), ml. per 100 g.	Average Hydrogen (Residual), ml. per 100 g.
A 6 S.W.G. (Iron silicate type).	Top (a)	0.10	0.010	7.6	} 8.0
	(b)	0.09	0.009	8.0	
	Base (a)	0.09	0.010	8.0	
	(b)	0.10	0.010	8.5	
B 12 S.W.G. (Iron silicate type).	Top (a)	0.14	0.028	6.5	} 5.8
	(b)	0.14	0.027	5.7	
	Base (a)	0.14	0.031	4.8	
	(b)	0.14	0.025	6.1	
B 8 S.W.G. (Iron silicate type).	Top (a)	0.14	0.014	3.9	} 4.1
	(b)	0.13	0.013	4.0	
	Base (a)	0.14	0.014	4.4	
	(b)	0.13	0.013	4.2	
C 12 S.W.G. (Rutile type).	Top (a)	0.09	0.020	6.9	} 6.8
	(b)	0.09	0.021	7.2	
	Base (a)	0.10	0.020	6.3	
	(b)	0.09	0.021	7.0	
D 12 S.W.G. (Rutile type).	Top (a)	0.11	0.030	7.4	} 6.6
	(b)	0.12	0.028	6.6	
	Base (a)	0.12	0.031	6.4	
	(b)	0.12	0.034	6.0	
E 12 S.W.G. (Ilmenite, manganese dioxide type).	Top (a)	0.13	0.038	16.5	} 15.8
	(b)	0.13	0.039	18.0	
	Base (a)	0.13	0.039	14.0	
	(b)	0.13	0.039	14.8	
F 6 S.W.G. (Rutile type).	Top (a)	0.06	0.055	1.3	} 1.5
	(b)	0.06	0.056	1.8	
	Base (a)	0.06	0.054	1.3	
	(b)	0.06	0.055	1.7	

It will be seen that for any given weld sample, the oxygen values obtained on specimens from widely different positions are extraordinarily consistent. This is no doubt due to the care taken to avoid even the smallest slag inclusions. The nitrogen results are similarly consistent. Most investigators, working with V-type samples, have reported a considerable difference in the nitrogen content of specimens taken from the top and bottom of the V. Possibly the shape of the channel in the present case may account for the fact that the nitrogen has not been found to show similar variations.

All welds made with the same make and size of electrode under the conditions used in the present investigation, show complete consistency in their oxygen and nitrogen contents. As will be seen from Table V., however, there is a considerable difference in both the oxygen and the nitrogen contents of welds made with different electrodes. The oxygen range has been found to extend from 0.06 to 0.14%, while the nitrogen varies from 0.010 to 0.055%. Differences in oxygen content were noted not only between welds made with electrodes of different types but also between those made with electrodes of the same type. (Compare the oxygen in samples made with electrodes *A* and *B*—iron silicate type—and that in samples made with electrodes *C*, *D*, *E*, and *F*—titanium oxide type.) Under standard conditions the oxygen content appears to depend only on the composition and, possibly, the amount, of the coating and not on that of the core wire. This is illustrated by electrode *B* of which two sizes, having different core-wire compositions (Table IX.), have been examined. The oxygen is the same for both. The nitrogen, however, appears to be influenced by core-wire size or composition (*see* Table V., electrode *B*, 8 and 12 S.W.G.). Possibly the size of bead affects the nitrogen content. Further consideration of the nitrogen in welds will be found in the section on the metallographic examination of welds.

Neither the oxygen nor the nitrogen in a weld sample bears any relationship to the amounts of these elements in the parent plate or electrode core wire (*see* Table IX.).

Total Hydrogen in the Welds.

Table V. shows that the residual hydrogen in a weld sample varies somewhat more, from position to position, than do the oxygen and nitrogen.

The total hydrogen in a particular sample is obtained by adding the amount extracted in the cold to that determined by vacuum-fusion analysis (average value, last column in Table V.), using the same sample throughout. The values for the electrodes examined are given in Table VI.

TABLE VI.—*Total Hydrogen in Welds.*

Electrode.	Hydrogen in Weld, ml. per 100 g.		
	Cold Extraction.	Vacuum Fusion.	Total.
<i>A</i> 6 S.W.G.	5.4	8.0	13.4
<i>B</i> { 12 S.W.G.	1.2	5.8	7.0
8 S.W.G.	2.3	4.1	6.4
<i>C</i> 12 S.W.G.	1.4	6.8	8.2
<i>D</i> 12 S.W.G.	2.8	6.6	9.4
<i>E</i> 12 S.W.G.	2.0	15.8	17.8
<i>F</i> 6 S.W.G.	3.2	1.5	4.7

For any particular make and size of electrode, determinations carried out on different weld samples showed that the total hydrogen is approximately constant from weld to weld made under the same controlled conditions (*see* Table VIII). Attempts were, therefore, made to correlate this total hydrogen with the potential hydrogen present during welding. No relationship could be established with the potential hydrogen in the flux coatings derived either from the "low-temperature water" (*i.e.*, water evolved at 600° C.) or from the "high-temperature water" (*i.e.*, water evolved above 600° C.). A reasonable proportionality was, however, found to exist between the total hydrogen in the weld and the total potential hydrogen present during welding (*i.e.*, total water as determined

at the fusion point of the coating, but ignoring the negligible amounts of hydrogen present in the base plate and core wire). Fig. 2 shows the total hydrogen in samples made with the different electrodes examined, plotted against the total potential hydrogen in the respective flux coatings, while Table VII. shows the values from which Fig. 2 was derived.

TABLE VII.—*Relation between Total Hydrogen in Weld and Potential Hydrogen in Coating.*

Electrode.		Total Hydrogen in Weld, ml. per 100 g. (a).	Potential Hydrogen in Coating, ml. per 100 g. (b).	$\frac{b}{a}$.
F	6 S.W.G.	4.7	850	180
B	8 S.W.G.	6.4	1150	180
B	12 S.W.G.	7.0	1300	186
C	12 S.W.G.	8.2	2100	256
D	12 S.W.G.	9.4	2200	234
A	6 S.W.G.	13.4	3000	224
E	12 S.W.G.	17.8	4400	247

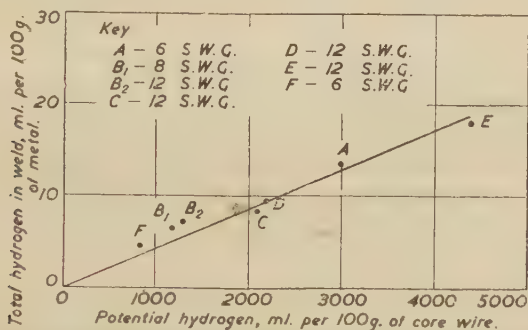


FIG. 2.—*Relation between Total Hydrogen in Weld and Potential Hydrogen in Flux Coating.*

In Fig. 2 a straight line has been used, as this appears to be the most suitable method of connecting the experimental points, in the absence of additional points nearer the origin than that corresponding to electrode *F*. It was considered desirable to extrapolate the line and draw it in such a way that it passed through the origin, since this should be a point on any curve connecting potential hydrogen with hydrogen in a weld. Confirmation of this was later found in an examination of a weld made using an anhydrous flux. In this case both the potential hydrogen in the flux and the total hydrogen in the weld deposit were extremely small.

From the foregoing it is apparent that the hydrogen content of weld metal deposited under the standard conditions used in the present investigation depends almost linearly on the potential hydrogen in the coating of the electrode and is independent of the form in which this potential hydrogen exists within the coating, *i.e.*, whether it results from decomposition of organic matter, such as cellulose, or is present combined with the mineral constituents. It seems very probable that the exact relationship between total hydrogen in the weld and potential hydrogen in the coating (*i.e.*, the actual slope of the line in Fig. 2), will depend on several factors

such as type of weld—channel, butt, or fillet—conditions of cooling between runs, &c., but for each set of conditions the curve should be of the same form as in Fig. 2, the only difference being that each will possess its own characteristic slope. The conclusions to be drawn from the present experiments should, therefore, be capable of general application.

One further point of interest is that in the present experiments the relation between total hydrogen and potential hydrogen has been found to be independent of core-wire size. It was anticipated that, owing to the different number of runs required to fill the experimental channel and the different amperages used for different sizes of core wire, the results for the various sizes would not all fit on one line as in Fig. 2, but on a series of lines radiating from the origin.

Hydrogen in Parent Plate.

The hydrogen content of the mild-steel plate used as the base on which weld metal was deposited was very low (Table IX.). During the extraction of hydrogen from a sample in the cold, the parent metal was still attached to the deposit. The values for the amount of gas evolved at room temperature therefore include, in every case, any hydrogen which may have been picked up by the parent plate—either during deposition of the weld metal or later, by diffusion from the deposit—and subsequently evolved from the plate. At the end of the cold extraction, when the deposit was separated from the plate, the residual hydrogen content of the latter was determined along with that of the specimens taken from the deposit itself. In every case it was found to be of the same order as in the original plate (about 0.8–1.0 ml. per 100 g.), implying that if any hydrogen had entered the parent material, it had diffused right through it by the time the cold extraction experiment was terminated.

It is legitimate, therefore, as has been done in the present case, to add the amount of hydrogen extracted in the cold from both deposit and parent plate to the amount of residual hydrogen in the deposit alone in order to obtain the total hydrogen resulting from a particular concentration of potential hydrogen during deposition.

DISTRIBUTION OF HYDROGEN IN WELD METAL.

In determining the total hydrogen in weld metal laid down with a particular electrode, the same sample was used throughout. It was found that while, as stated above, the total hydrogen is approximately constant from weld to weld, the proportion of this total which is evolved in the cold varies considerably. The residual hydrogen (*i.e.*, that subsequently determined by vacuum-fusion analysis) shows, of necessity, similar variations, in order that the total may remain constant.

This effect is well illustrated by the results obtained using electrode C (12 S.W.G.) and shown in Table VIII. Four separate welds made under identical conditions were examined.

TABLE VIII.—*Proportions of Total Hydrogen Obtained by Cold Extraction and by Vacuum Fusion.*

Weld Sample (Using Elec- trode C).	Hydrogen in Weld, ml. per 100 g.		Total.
	Cold Extraction.	Vacuum Fusion.	
1	1.4	6.8	8.2
2	3.1	5.5	8.6
3	2.2	5.7	7.9
4	1.6	6.7	8.3

Similar variations were found whenever two or more samples were prepared using any one of the particular electrodes investigated. An interesting implication is that the amount of hydrogen evolved in the cold has no relation to the total present. In fact, more may be evolved from a deposit having a lower total hydrogen than from one in which the total is higher (*cf.* welds made with electrodes *C* and *F* in Table VI.), but it was noted that, except in a few cases, it does not exceed 50% of the total.

This variability in the amount of hydrogen evolved in the cold from similar samples appears to be a general phenomenon which could not be controlled by the operator. It seems possible that it is due to a very fine porosity within weld metal, arising from causes about which very little is at present known, such as, for example, variations in the temperature or other electrophysical characteristics of the arc during welding.

CHEMICAL EXAMINATION OF WELDS.

Chemical Analyses.

Chemical analyses were carried out on the mild-steel parent plate, on representative samples of each make and size of electrode core wire, and on the weld deposits made with them. In the case of a weld, turnings from the various machining operations were mixed to give an average sample. The results are given in Table IX.

Distribution of Oxygen in the Oxide Inclusions.

The distribution of oxygen in the inclusions in the weld samples was determined by the alcoholic iodine method.³ The extraction of the oxides was carried out at a temperature of 65° C., which usually ensures the decomposition of other inclusions such as sulphides, &c. The results are given in Table X.

With ordinary steel samples, the minor constituents of the residue, *viz.*: chromium, phosphorus, and titanium, are disregarded when calculating the total oxygen. In the present case, where the samples have a high total oxygen content and a low carbon content, it is possible that the minor constituents are present to some extent as oxides. The amounts of these elements have, therefore, been calculated to oxides and the oxygen equivalents included in the total oxygen as given by the alcoholic iodine method. The values obtained are in very good agreement with those given by the vacuum-fusion method (Tables V. and IX.) which are included in Table X. for ease of comparison.

A critical examination of the results in Tables IX. and X. reveals several points of interest.

Minor Constituents of the Residue : Cr_2O_3 , P_2O_5 , TiO_2 (and Al_2O_3).

The chromium and phosphorus found bear no relation to the amounts of these elements determined by ordinary chemical analysis of the weld metal, but this feature has been noted, to some extent, in the examination of ordinary steels by the alcoholic iodine method.³

All the coatings are stated to contain alumina (in the form of silicates). Since very little, if any, is found in the oxide inclusions, it is evidently slagged off. Only a very small proportion of the titanium present in the coatings of electrodes *C*, *D*, *E*, and *F* enters the deposits made with them, and the titania in the coatings must, therefore, be retained in the slag.

Major Constituents of the Residue : SiO_2 , FeO , and MnO .

The amount of SiO_2 found in the residues varies from 0.44% in the case of electrode *B*, to 0.122% in electrode *D*, and as it contains a high propor-

TABLE IX.—*Analyses of Plate, Core Wires, and Weld Deposits.*

	Carbon. Wt.-%.	Silicon. Wt.-%.	Sul- phur. Wt.-%.	Phos- phorus. Wt.-%.	Manga- nese. Wt.-%.	Nickel. Wt.-%.	Chrom- ium. Wt.-%.	Molyb- denum. Wt.-%.	Titan- ium. Wt.-%.	Oxygen (Vacuum Fusion). Wt.-%.	Hydro- gen. ^a Ml. per 100 g.	Nitrogen. Wt.-%.	
												Vacuum Fusion.	Chem- ical.
Mild-steel base plate . . .	0.18	0.043	0.042	0.032	0.53	<0.01	<0.02	Nil	Nil	0.010	0.7	0.002	0.002
Electrode A { Core wire . . .	0.12	0.010	0.026	0.017	0.49	0.07	0.05	Nil	Nil	0.012	0.7	0.003	0.003
(6 S.W.G.) { Weld . . .	0.09	0.057	0.026	0.035	0.47	0.09	0.11	Nil	Nil	0.10	13.4	0.010	0.010
Electrode B { Core wire . . .	0.08	0.020	0.016	0.012	0.59	0.05	0.05	Nil	Nil	0.008	0.8	0.003	0.002
(12 S.W.G.) { Weld . . .	0.05	0.040	0.030	0.044	0.40	0.04	0.12	Nil	Nil	0.14	7.0	0.028	0.025
Electrode B { Core wire . . .	0.07	<0.010	0.027	0.030	0.34	0.03	0.08	Nil	Nil	0.010	0.6	0.003	0.002
(8 S.W.G.) { Weld . . .	<0.05	0.020	0.029	0.036	0.24	0.05	0.15	Nil	Nil	0.13 ₅	6.4	0.013 ₅	0.014
Electrode C { Core wire . . .	0.07	0.015	0.025	0.005	0.33	0.06	0.06	Nil	Nil	0.017	0.9	0.003	0.003
(12 S.W.G.) { Weld . . .	0.07	0.060	0.033	0.025	0.47	<0.01	0.16	Nil	<0.01	0.09	8.2	0.020 ₆	0.025
Electrode D { Core wire . . .	0.12	0.020	0.026	0.018	0.41	0.21	0.06	Nil	Trace	0.022	0.7	0.003	0.003
(12 S.W.G.) { Weld . . .	0.05	0.060	0.043	0.026	0.23	0.02	0.21	Nil	0.01	0.12	9.4	0.031	0.028
Electrode E { Core wire . . .	0.09	0.010	0.028	0.008	0.46	0.06	0.04	Nil	Nil	0.011	0.5	0.003	0.004
(12 S.W.G.) { Weld . . .	0.07	0.043	0.013	0.034	0.24	0.09	0.16	Nil	<0.01	0.13	17.8	0.039	0.041
Electrode F { Core wire . . .	0.05	<0.010	0.022	0.016	0.52	0.08	0.08	Nil	Nil	0.015	1.0	0.003	0.003
(6 S.W.G.) { Weld . . .	0.05	0.11	0.029	0.036	0.50	0.02	0.08	Nil	0.02	0.06	4.7	0.055	0.050

* For the plate and core wires, the hydrogen values were obtained by the vacuum-fusion method. For the weld samples, the figures represent the sum of the quantity evolved in the cold and the residual amount subsequently determined by the vacuum-fusion method.

TABLE X.—*Analyses of Iodine Residues from the Welds.*

Electrode.	Oxide in the Residue and Equivalent Oxygen Value, Expressed as a Percentage of the Weld Metal.														Total Oxygen. %.
	SiO ₂ .		FeO.		Al ₂ O ₃ .		MnO.		Cr ₂ O ₃ .		P ₂ O ₅ .		TiO ₂ .		
	Oxide.	Oxy- gen.	Oxide.	Oxy- gen.	Oxide.	Oxy- gen.	Oxide.	Oxy- gen.	Oxide.	Oxy- gen.	Oxide.	Oxy- gen.	Oxide.	Oxy- gen.	
A	0.099	0.053	0.016	0.003 _s	0.005	0.002	0.123	0.028	...	...	0.002	0.001	...	...	0.09
B	0.044	0.024	0.200	0.044	0.002	0.001	0.162	0.036	0.026	0.008	0.025	0.014	...	...	0.13
C	0.049	0.026	0.192	0.043	N.D.	N.D.	0.145	0.033	Oxygen approx. 0.020			0.003	0.002	...	0.14
D	0.099	0.053	0.011	0.002	0.008	0.004	0.115	0.026	0.001	0.000 ₄	0.003	0.002	0.014	0.006	0.09
E	0.122	0.065	0.023	0.005	...	...	0.158	0.035	0.011	0.004	0.002	0.001	0.015	0.006	0.12
F	0.077	0.041	0.179	0.040	...	...	0.177	0.040	0.011	0.003	0.019	0.011	0.007	0.003	0.13
F	0.060 ₅	0.032	0.004	0.001	...	...	0.091	0.020	0.005	0.002	0.002	0.001	0.018	0.007	0.06

N.D. = Not determined.

tion of oxygen it can, in each case, be considered a major constituent. Its relation with the silicon content of the core wire is discussed below.

The content of FeO shows greater variation, being low in the residues from welds *A*, *C*, *D*, and *F* and high in those from *B* and *E*. The amount of FeO evidently depends on a number of factors and it is obvious that further work is necessary in order to determine the influence of the coating composition on the iron oxide content of the weld.

All the residues contain a high proportion of manganese oxide (0.091–0.177%), and there is not as much variation in the percentage as in the case of oxide of iron.

An important development of this work is that the true elemental silicon and manganese content of the weld can be determined.

The values obtained by ordinary chemical analysis show that, normally, the weld is considerably richer in silicon than is the core wire used for deposition, but the silica values obtained by the alcoholic iodine method, when compared with the silicon as determined by chemical analysis, indicate that this richness in silicon is illusory, and that, in fact, the deposits examined contain only a very small percentage of elemental silicon. An exception is weld metal laid down with electrode *F*. The true silicon contents of the various deposits are shown in Table XI.

TABLE XI.—*True Silicon Content of Weld Deposits.*

Electrode Used.		Silicon by Chemical Analysis. %. (Table IX.) (a).	Si Equivalent of SiO ₂ Determined by Iodine Method. %. (Table X.) (b).	True Silicon Content of Weld. %. (a - b).
<i>A</i>	6 S.W.G.	0.057	0.046	0.011
<i>B</i>	{ 12 S.W.G.	0.040	0.020	0.020
	{ 8 S.W.G.	0.020	0.023	...
<i>C</i>	12 S.W.G.	0.060	0.046	0.014
<i>D</i>	12 S.W.G.	0.060	0.057	0.003
<i>E</i>	12 S.W.G.	0.043	0.036	0.007
<i>F</i>	6 S.W.G.	0.110	0.028	0.082

Similarly, the true manganese contents of the deposits are very much lower than is suggested by ordinary chemical analysis. In this case, however, it is also necessary to take into consideration the amount of manganese present as manganese sulphide, and it has been assumed that all the sulphur is in the form of MnS (evidence for this assumption is given later). The true manganese contents of the welds are given in Table XII.

TABLE XII.—*True Manganese in Weld Deposits.*

Electrode Used.		Manganese by Chemical Analysis. %. (Table IX.) (a).	Mn Equivalent of MnO Determined by Iodine Method. %. (Table X.) (b).	Mn Equivalent of Sulphur. %. (Table IX.) (c).	True Manganese in Weld. % a - (b + c).
<i>A</i>	6 S.W.G.	0.47	0.095	0.045	0.33
<i>B</i>	{ 12 S.W.G.	0.40	0.126	0.052	0.22
	{ 8 S.W.G.	0.24	0.113	0.050	0.08
<i>C</i>	12 S.W.G.	0.47	0.089	0.057	0.32
<i>D</i>	12 S.W.G.	0.23	0.123	0.074	0.03
<i>E</i>	12 S.W.G.	0.24	0.137	0.022	0.08
<i>F</i>	6 S.W.G.	0.50	0.070	0.050	0.38



FIG. 3.—Inclusion in Weld (Electrode *B*). Un-etched. $\times 1500$.



FIG. 4.—Inclusions in Weld (Electrode *D*). Un-etched. $\times 1500$.



FIG. 5.—Inclusions in Weld (Electrode *E*). Un-etched. $\times 1500$.

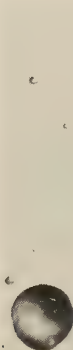


FIG. 6.—Inclusions in Weld (Electrode *C*). Un-etched. $\times 1500$.



FIG. 7.—Weld (Electrode *B*), as welded. Etched in solution of nitric acid in alcohol. $\times 500$.

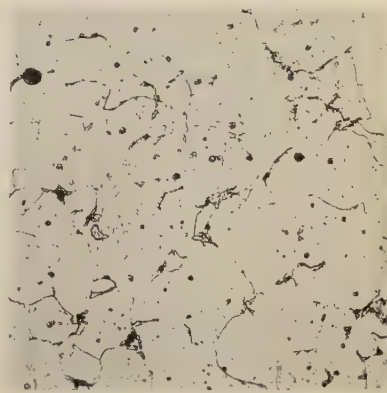


FIG. 8.—Weld (Electrode *B*), heated at 950° C. Etched in solution of nitric acid in alcohol. $\times 500$.

(Micrographs reduced to four-fifths linear in reproduction.)

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FIG. 9.—Weld (Electrode *A*), heated at 950° C. for 15 min., followed by 26 days at 200° C. Etched in a solution of nitric acid in alcohol. $\times 1500$.

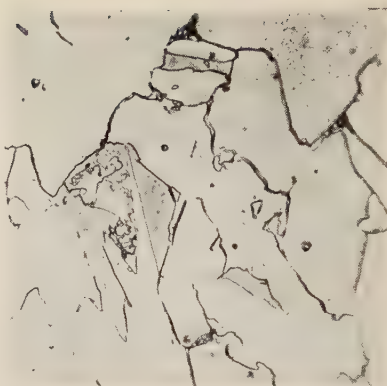


FIG. 10.—Weld (Electrode *F*), heated at 950° C. for 15 min., followed by 26 days at 200° C. Etched in a solution of nitric acid in alcohol. $\times 1500$.

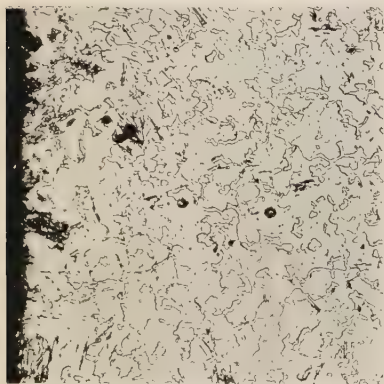


FIG. 11.—Weld (Electrode *B*), after McQuaid-Ehn test. Etched in a solution of nitric acid in alcohol. $\times 150$.



FIG. 12.—Parent Plate, after McQuaid-Ehn test. Etched in a solution of nitric acid in alcohol. $\times 150$.



FIG. 13.—Weld (Electrode *B*), heated at 950° C. for 15 min., followed by 26 days at 200° C. Etched in a solution of nitric acid in alcohol. $\times 1500$.

(Micrographs reduced to four-fifths linear in reproduction.)

[Sloman, Rooney, and Schofield.]



FIG. 15.—Sulphur Print of a Typical Arc-Weld. $\times 1$.



FIG. 16.—Sulphur Print of a Typical Oxy-Acetylene Weld. $\times 1$.



FIG. 14.—Sulphur Print of Section through Weld (Electrode *D*) and Plate. $\times 1$.



FIG. 17.—Typical Inclusions in Oxy-Acetylene Weld shown in Fig. 16. Unetched. $\times 1500$.

FIG. 18.—Typical Inclusions in Parent Plate. Unetched. $\times 300$.



FIG. 19.—Same Group of Inclusions in Plate as shown in Fig. 18. Unetched. $\times 60$.



FIG. 20.—Photomicrograph of Sulphur Print of same Field as shown in Fig. 19. $\times 60$.

(Micrographs reduced to four-fifths linear in reproduction.)

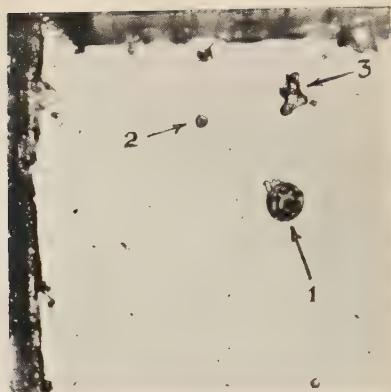


FIG. 21.—Inclusions in Weld (Electrode B). Unetched. $\times 300$.



FIG. 22.—Same Group of Inclusions in Weld (Electrode B) as shown in Fig. 21. Unetched. $\times 60$.

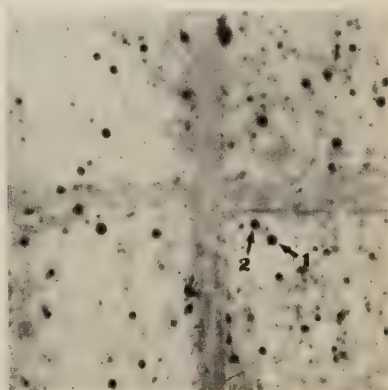


FIG. 23.—Photomicrograph of Sulphur Print of same Field as shown in Fig. 22. $\times 60$.

Attention may be drawn at this stage to the results obtained with electrode *B*, which, up to the present, is the only one which has been examined in two core-wire sizes. Table X. shows that the total and form of distribution of the oxygen is the same for both sizes, which suggests that these values are a function of the coating composition (a constant for both sizes). The total manganese (Table IX.) and the elemental manganese (Table XII.) are, however, both different in the two welds, the differences approximately following those in the percentages of total manganese in the two sizes of core wire (Table IX.). A similar relationship holds for the amount of elemental silicon. It would appear, therefore, that the amounts of elemental manganese and silicon can be varied by altering the manganese and silicon contents of the core wire while keeping the composition and relative amount of the coating constant.

Identification by X-ray Methods of Residues Extracted by the Alcoholic Iodine Method.

For this purpose, the alcoholic iodine extraction was carried out at a temperature of about 30° C. in order to retain as much as possible of the inclusions in their original crystalline form and avoid breaking up or decomposing them. This temperature of extraction also tends to retain undecomposed sulphides in the residues. The residues thus prepared were examined by X-ray methods, constituents in the residue being identified by comparison of the photographs with those of powdered pure substances taken under similar conditions. The results of the X-ray examinations are summarized in Table XIII. For comparison, the principal oxide constituents of each weld as given by the alcoholic iodine method operated at 65° C. (Table X.) and calculated as percentages of the total residues, are included. When expressed in this way, the agreement between the results by the alcoholic iodine and the X-ray methods is very striking.

TABLE XIII.—*Comparison between Analytical and X-ray Examination of Residues.*

Electrode Used.	Principal Oxide Constituents of the Residue (at 65° C.).			Compounds Identified by X-ray Examination of the Residue (at 30° C.).
	FeO. %.	MnO. %.	SiO ₂ . %.	
<i>A</i> 6 S.W.G. .	6	50	41	(Mn,Fe)O.SiO ₂ + MnS
<i>B</i> { 12 S.W.G. .	44	35	10	(Fe,Mn)O + 2(Fe,Mn)O.SiO ₂
8 S.W.G. .	44	33	11	(Fe,Mn)O + 2(Fe,Mn)O.SiO ₂
<i>C</i> 12 S.W.G. .	4	46	40	(Mn,Fe)O.SiO ₂ + MnS
<i>D</i> 12 S.W.G. .	7	48	37	(Mn,Fe)O.SiO ₂ + MnS
<i>E</i> 12 S.W.G. .	38	38	16	(Fe,Mn)O + 2(Fe,Mn)O.SiO ₂
<i>F</i> 6 S.W.G. .	2	50	34	(Mn,Fe)O.SiO ₂ + MnS

In the photographs of the residues from welds made with electrodes *A*, *C*, *D*, and *F*, the lines were rather faint, but two compounds could be identified. The main pattern corresponded to that given by a silicate of the rhodonite type (MnO.SiO₂) though the lines were slightly displaced as compared with those given by both synthetic and natural rhodonite. The shift in the spacings of the lines probably indicates that some small proportion of the manganese has been displaced by iron; hence the formula given in Table XIII.: (Mn,Fe)O.SiO₂. The faintness of the pattern for this compound is probably due to a large proportion of the silicate being glassy rather than crystalline in character.

The second constituent identified was pure manganese sulphide. The lines corresponding to this compound were very faint, probably because of the small amount present in the residues. (MnS is partially decomposed by the iodine-solution even at a temperature of 30° C.) No indication of the presence of iron sulphide or of a solid solution of manganese and iron sulphides was found, the pattern corresponding, within the limits of experimental accuracy, to pure manganese sulphide.

In the photographs of the residues from welds made with electrode *B* (both core-wire sizes) and *E*, the lines were very much stronger and, once again, two compounds were easily identified. One gave a pattern which is intermediate in spacing between those for pure FeO and pure MnO, and is probably a solid solution of the two oxides, represented in Table XIII. by the formula: $(\text{Fe,Mn})\text{O}$. The other gave a pattern very slightly displaced as compared with that given by a synthetic sample of fayalite: $2\text{FeO} \cdot \text{SiO}_2$. There is probably a slight displacement of iron by manganese; hence the formula used: $2(\text{Fe,Mn})\text{O} \cdot \text{SiO}_2$. In these residues no indication of a sulphide was observed on the X-ray photographs, possibly because the small amount present was masked by the strong patterns given by the other constituents. Each residue prepared at the low temperature (30° C.) for X-ray examination was tested chemically for sulphide. Its presence was revealed in every case.

There can be little doubt that the form of distribution of the oxygen and the type or types of oxide inclusions are a function of the electrode coating. Ignoring electrode *A* for the moment, reference to Tables I. and XIII. shows that, when the coating contains a large amount of titanium and little iron—electrodes *C*, *D*, and *F*—the inclusions are of the $\text{MnO} \cdot \text{SiO}_2$ type. When the coating contains an appreciable amount of iron—electrode *B*—the inclusions consist of a combination of the FeO and $2\text{FeO} \cdot \text{SiO}_2$ types. In electrode *E* there appears to be sufficient iron (associated with titanium as ilmenite) to overcome the effect of titanium and to produce inclusions characteristic of an iron-base coating. The effect of manganese dioxide in this coating is not clear but there appears to be little difference in its action as compared with ferro-manganese. Electrode *A* appears to occupy an anomalous position, having an iron-oxide type coating but giving rise to inclusions typical of the titanium-oxide type. A possible explanation of the difference between the inclusions produced by electrodes *A* and *B*, which according to Table I. have coatings of similar type, may be due to the very much higher proportion of coating on *B* as compared with *A* (Table III.), or to the reducing action of the cellulose present in the coating of electrode *A*. This point requires further elucidation.

The relation between the types of oxide inclusions and the mechanical and physical properties of mild-steel weld deposits has not been investigated.

METALLOGRAPHIC EXAMINATION OF WELDS.

Microstructure.

Large numbers of uniformly dispersed inclusions were present in each deposit. The major proportion was too small to permit detailed examination even at a high magnification (see Figs. 5 and 6), but generally they appeared to be translucent. The remainder of the inclusions were sufficiently large for their structure to be resolved and at least three or four types were present in each deposit. The maximum diameter of any inclusion observed did not exceed 0.00035 in. It was difficult to determine the relative amounts of the different types present in any particular deposit, but Figs. 3-6 show typical examples.

The ground-mass of the duplex inclusions in Figs. 3 and 5 is slightly

translucent, while Fig. 4 shows a type which is opaque and has an irregular outline. Fig. 6 shows two further examples; of the large inclusions, the upper appears to have a rough surface and tends to polish in relief so that it is difficult to focus the whole surface simultaneously, while the lower one is homogeneous and translucent. No manganese sulphide inclusions of the type normally found in steel were identified in any of the deposits, but sulphur prints indicated that such inclusions were present in an extremely fine form.

It should be noted that the presence of each of the three or four types of large inclusion discussed above was observed in every deposit examined in sufficient detail, but it was not possible to establish any relationship between the results of the chemical and X-ray analyses of the alcoholic iodine residues and the relative amounts of any particular type of inclusion in a given deposit.

The vertical sections of each weld had, in general, very fine grain-size (about 9 A.S.T.M.), except for a layer about $\frac{1}{8}$ in. deep from the top surface. The grain-size did not change appreciably after normalizing at 950° C. It is probable that during each successive run, the heat was sufficient to normalize the metal deposited previously.

The constituents, other than the inclusions referred to above, varied with the carbon and nitrogen contents and did not resemble lamellar pearlite in any of the deposits. Figs. 7 and 8 show the deposit made with electrode *B* (0.025% nitrogen and 0.05% carbon) before and after normalizing respectively; in both instances a constituent which somewhat resembles spheroidized pearlite is present. In the deposit made with electrode *A* (0.01% nitrogen and 0.09% carbon), the main constituent resembles sorbitic pearlite, but some of the spheroidized constituent is also present (Fig. 9). The deposit made with electrode *F* (0.055% nitrogen and 0.05% carbon) shows a constituent which appears in the form of angular patches, which etch light brown in alcoholic nitric acid, in addition to the spheroidized constituent (Fig. 10). In all cases the spheroidized constituent was blackened by a boiling solution of alkaline sodium picrate. The effect of nitrogen on the appearance of the pearlite has previously been reported by Schuster⁴ and others.

McQuaid-Ehn tests were carried out on deposits made with electrodes *B* (12 S.W.G.), *D*, and *E*. In each case a very abnormal structure was found (Fig. 11) as compared with a similar test on the parent plate material (Fig. 12) and the electrode core wires. Similar tests have not so far been carried out on welds made with the remaining electrodes of the series.

Effect of Low-Temperature Heat-Treatment on the Hardness and Microstructure of the Welds.

It will be recalled that one of the machining operations discussed earlier was the removal, by cuts in a plane at right angles to the length of the deposit, of about 1 in. from each end. For the present examination, a small specimen about $\frac{3}{8}$ in. sq. and about $\frac{1}{4}$ in. thick was taken from the middle of the machined face of one or other of these end pieces. Similar specimens were prepared from each deposit and hardness measurements on the sections were made both before and after normalizing, and also after normalizing followed by heating for 26 days at 200° C. The results, together with the nitrogen contents, are given in Table XIV.

Normalizing at 950° C. for 15 min. did not cause any significant reduction in hardness, except in the case of the deposit made with electrode *F* and possibly in the welds made with electrodes *C* and *D*, respectively. Heat-treatment for 26 days at 200° C. (air cooled) subsequent to normalizing, resulted in an appreciable reduction in hardness of all the deposits except that made with electrode *A*. Microscopical examination revealed

TABLE XIV.—*Effect of Heat-Treatment on Hardness of Weld Metal.*

Electrode.	Hardness Number (Mean of 2 Readings) (136° Angle Diamond Pyramid, 30 kg. Load.				
(1).	(2).	(3).	(4).	(5).	(6).
	Deposit as Laid Down.	Heated at 950° C., 15 min. Air Cooled.	Heated at 950° C., 15 min. Air Cooled, Followed by 26 Days at 200° C.	Hardness Difference Between Cols. 3 and 4.	Nitrogen Content. %.
<i>A</i> 6 S.W.G. .	132	125	125	0	0.010
<i>B</i> 12 S.W.G. .	149	149	122	27	0.028
<i>B</i> 8 S.W.G. .	134	131	116	15	0.014
<i>C</i> 12 S.W.G. .	151	141	126	15	0.021
<i>D</i> 12 S.W.G. .	152	144	127	17	0.031
<i>E</i> 12 S.W.G. .	134	134	111	23	0.039
<i>F</i> 6 S.W.G. .	176	159	135	24	0.055

the precipitation of numerous needles (Fig. 13) in all cases except in deposits made with electrodes *A* and *F*, respectively.

In this connection it is noteworthy that while the deposit made with electrode *F* has the highest nitrogen of the series and might, therefore, be expected to show the most intense precipitation of needles, it also contains the highest silicon and manganese (both total and elemental, *see* Tables XI. and XII.). Both these elements tend, according to Schuster,⁴ to inhibit the formation of needles, and this may explain the apparent anomaly in the effect of the low-temperature heat-treatment on this weld. With regard to the deposit made with electrode *A*, this has a very low nitrogen content so that the precipitation of needles would be expected to be small, apart from the fact that it also contains relatively high silicon and manganese.

In column (5), Table XIV., are given the differences between the hardness of the welds after normalizing, and after the low-temperature heat-treatment subsequent to normalizing, while in column (6) are given the nitrogen contents. It appears that there is a tendency for the hardness differences to increase with increasing nitrogen, but it is probable that other undetermined factors are involved.

Condition of the Sulphides in the Parent Plate and Weld Metal.

In all the weld samples prepared during the course of the work, the deposits show a paler sulphur print than does the adjacent plate material, even when the sulphur contents of the deposit and plate are similar. For example, Fig. 14 shows a sulphur print of a section through the deposit (electrode *D*) and plate in which the sulphur contents of weld and plate are respectively 0.043 and 0.042%.

Attempts have been made to ascertain the reasons for this difference in the sulphur prints. There appeared to be a possibility that, owing to the high proportion of oxygen present in the welds, the sulphur might be in a partially oxidized condition. In order to check this possibility, the sulphur in one deposit was determined by the evolution method, which, like sulphur printing, depends on the formation of hydrogen sulphide when the metal is acted upon by acid. The results agreed with those obtained

by the normal gravimetric method for sulphur, thus indicating that the sulphur is present entirely as sulphide in both deposit and parent plate.

In order to ascertain whether sulphur prints of commercial mild-steel welds show such differences, an examination was made of the prints from several manual and automatic process arc-welds, and several oxy-acetylene welds. The parts of the sulphur prints corresponding to the weld deposits of all the arc-weld samples were markedly paler than the parts which corresponded to the plates, thus confirming the observations made on the samples prepared specially for the present investigation. On the contrary, however, the sulphur prints from the oxy-acetylene welds showed no such differences between deposit and plate. Figs. 15 and 16 show typical examples of prints from arc and oxy-acetylene welds respectively.

It seemed possible that the difference between the sulphur prints from the two types of weld was connected with the presence of a flux during arc-welding. An attempt was accordingly made to prepare an oxy-acetylene weld using a covered electrode (electrode D). The results were inconclusive, as it was found that the gas pressure necessary to melt the electrode tended to blow the flux away so that it did not cover the deposit in the normal way. The same electrode, stripped of its coating, produced an oxy-acetylene weld having a sulphur print of the typical oxy-acetylene type. The composition of the electrode wire is, therefore, not a significant factor in the present connection.

A further possibility, namely, rapidity of cooling, was then considered. For this, a piece of the parent plate was taken to a temperature of about 1700° C. and cast into a V-shaped channel made in a further piece of the same plate. The amount of metal cast was very small compared with the mass of the mould and solidification was almost instantaneous. Once again, however, the order of density of the part of the sulphur print corresponding to the melted metal was the same as that corresponding to the ordinary plate.

Microscopical examination showed that the sulphide spots in the prints of arc-weld deposits were extremely fine and numerous, whereas those in the prints from oxy-acetylene welds and the chilled plate were relatively much larger and less numerous. A similar examination of the actual deposits themselves showed significant differences in the type of inclusions present. The arc-weld deposits contained a greater proportion of very fine inclusions than did the oxy-acetylene welds, and these inclusions were generally similar to those in the deposits made for the present investigation. No particles of manganese sulphide could be detected even at high magnification. On the other hand, the oxy-acetylene deposits and the chilled plate metal showed numerous inclusions of manganese sulphide, but none of the larger inclusions resembled those found in the arc-weld deposits. Compare Fig. 17, which shows typical inclusions in an oxy-acetylene weld, with Figs. 3-6, which show those of arc-welds. In general, the larger inclusions in the oxy-acetylene weld deposits and in the chilled plate metal were similar to those present in cast steel except that they were somewhat smaller. It was not possible to determine whether any of the very fine particles present in both types of weld were similar.

An attempt has been made to correlate the inclusions observed in polished specimens of the parent plate and deposits with the sulphide spots in photomicrographs of the sulphur prints, particularly in order to ascertain which inclusions in the deposits give rise to sulphide spots. The experiments have been carried out on two of the welds in the present series. Similar results were obtained in each case and it is proposed to describe and illustrate only one of the experiments.

Fig. 18 shows a group of inclusions in the parent plate at a magnification of 300 dia. The inclusions are typical of those normally encountered in

mild steel and are considered to consist of a solid solution of manganese and iron sulphides. The same group of inclusions is shown in Fig. 19 at a magnification of 60 dia.; two crossed scratches made on the specimen after polishing indicate the position of the inclusions. Fig. 20 is a photomicrograph of a sulphur print of the same area and at the same magnification as Fig. 19. It will be seen that the group of inclusions shown in Figs. 18 and 19 has given rise to one large sulphur spot indicated by the arrow in Fig. 20. Previous experiments indicated that had the conditions of taking the sulphur print been modified, the individual spots in the group of inclusions would have shown up on the sulphur print. The conditions of taking the print were, however, adjusted to suit the deposit rather than the parent plate.

Similarly, Fig. 21 shows a group of three inclusions in the deposit marked respectively (1), (2), and (3), at a magnification of 300 dia. Inclusions (1) and (2) are duplex and apparently opaque and (3) is homogeneous and translucent. The same group is shown in Fig. 22 at a magnification of 60 dia., and a photomicrograph of the sulphur print of the same field and at the same magnification in Fig. 23. It is apparent that both inclusion (1) and (2) have given rise to sulphide spots of nearly the same size although the actual sizes of the inclusions themselves (Fig. 21) differ considerably. On the other hand, inclusion (3) has not given rise to a spot at all. It seems probable, therefore, that of the three inclusions, (2) contains the greatest amount of sulphide, (1) an intermediate amount, and (3) the least; apparently it is free from sulphide.

Thus the chief reason why the sulphur prints of the arc-weld deposits show such fine sulphide spots is that the sulphide in these deposits is present either in association with other inclusions or else as very small particles—too small to be identified under the microscope, and which may or may not also be associated with the other inclusions. From such a material it would be expected that the macroscopic appearance of the numerous small and faint spots would be much paler than that due to fewer but larger and denser spots. The cause of this type of sulphide inclusion, which is apparently characteristic of all arc-welds made with covered electrodes or with a powdered flux, is not understood.

EXAMINATION OF WELDS MADE BY TWO AUTOMATIC PROCESSES.

An examination of mild-steel deposits laid down by two automatic processes was conducted along lines similar to, but less exhaustive than, those of the main investigation. The equipment necessary for making the welds was not available at the National Physical Laboratory and arrangements were accordingly made through the Advisory Service on Welding for the welds to be prepared elsewhere.

In both cases the deposits were of the deep channel type using mild-steel plate. In process (1) a bare electrode and an anhydrous powder flux consisting essentially of calcium silicate are employed, while in process (2) a covered electrode having a coating of the fluoride type with ferro-alloy admixture is used.

Chemical and Vacuum-Fusion Analyses.

In Table XV. are given the chemical and vacuum-fusion analyses of the electrode wires and weld deposits.

The moisture content of the anhydrous flux used in process (1) was very low (0.1% by weight), and although the hydrogen in the weld could not be determined until 4 days after deposition it may be assumed that the metal was essentially free from hydrogen even immediately after deposition. If this were not so, it would be difficult to explain why, contrary to experi-

TABLE XV.—Analyses of Electrodes and Welds Made by the Automatic Processes.

Process.	Material.	Carbon. %.	Silicon. %.	Sulphur. %.	Phosphorus. %.	Manganese. %.	Nickel. %.	Chromium. %.	Molybdenum. %.	Titanium. %.	Oxygen. %.	Hydrogen. ml./100 g.	Nitrogen. %.	
													Vacuum Fusion.	Chemical.
(1)	Electrode	0.13	0.08	0.015	0.033	1.92	N.D.	N.D.	N.D.	Nil	0.007	Trace	0.006	0.005
(2)	Weld	0.09	0.34	0.037	0.063	1.05	N.D.	N.D.	N.D.	Trace	0.084	Trace	0.010	0.008
	Electrode	0.16	0.02	0.028	0.025	0.53	0.22	0.10	Nil	Nil	N.D.	N.D.	N.D.	N.D.
	Weld	0.12	0.34	0.042	0.028	0.80	0.19	0.15	0.19	0.012	0.038	1.2	0.015	0.013

N.D. = Not determined.

TABLE XVI.—Analyses of Iodine Residues from Welds by the Automatic Processes.

Oxide in the Residue and Equivalent Oxygen Value Expressed as a Percentage of the Weld Metal.																	Total Oxygen.	
Pro- cess.	SiO ₂ .		FeO.		Al ₂ O ₃ .		MnO.		Cr ₂ O ₃ .		P ₂ O ₅ .		TiO ₂ .		Iodine Fusion Method. %.	Vacuum- Fusion Method. %.		
	Oxide.	Oxygen.	Oxide.	Oxygen.	Oxide.	Oxygen.	Oxide.	Oxygen.	Oxide.	Oxygen.	Oxide.	Oxygen.	Oxide.	Oxygen.				
(1)	0.115	0.061	0.005	0.001	...	...	0.098	0.022	0.001	0.000 ₅	0.005	0.003	...	...	0.087	0.084
(2)	0.042	0.022	0.004	0.001	0.005	0.002 ₅	0.048	0.011	...	...	0.002 ₅	0.001	0.017	0.007	0.044	0.038

ence both with weld metal and cast steel, the gas should have been completely lost in so short a time.

The coating of the electrode used in process (2) contained about $1\frac{1}{2}\%$ by weight of total water and contained no other source of hydrogen. It was not possible to examine the weld until about 3 weeks after deposition. An unknown amount may, therefore, have been lost.

Distribution of Oxygen in the Inclusions.

The distribution of the oxygen was determined by the alcoholic iodine method operated at 65°C . and the results are given in Table XVI.

There is very good agreement between the total oxygen as determined by the alcoholic iodine and vacuum-fusion methods. The major constituents of the residues (Table XVII.) are in both processes manganous oxide and silica.

TABLE XVII.—*Comparison between Analytical and X-ray Examination of the Residues.*

Process.	Principal Oxide Constituents of the Residue (at 65°C .)			Compounds Identified by X-ray Examination of the Residue (at 30°C .)
	FeO. %.	MnO. %.	SiO ₂ . %.	
(1)	2	44	51 (P ₂ O ₅ , 2%)	MnO.SiO ₂ + MnS
(2)	3	41	35	MnO.SiO ₂ + MnS

X-ray examination of residues obtained by operating the alcoholic iodine method at 30°C . showed the presence of a silicate of the rhodonite type (MnO.SiO₂) and also manganese sulphide.

The elemental silicon and manganese (assuming all the sulphur in the welds is present as manganese sulphide) were calculated as before and are given in Tables XVIII. and XIX.

TABLE XVIII.—*True Silicon in Weld Deposits.*

Process.	Silicon by Chemical Analysis. %. (Table XV.) (a).	Si Equivalent of SiO ₂ Determined by Iodine Method. %. (Table XVI.) (b).	True Silicon in Weld. %. (a - b).
(1)	0.34	0.054	0.286
(2)	0.34	0.02	0.32

TABLE XIX.—*True Manganese in Weld Deposits.*

Process.	Manganese by Chemical Analysis. %. (Table XV.) (a).	Mn Equivalent of MnO Determined by Iodine Method. %. (Table XVI.) (b).	Mn Equivalent of Sulphur. (Table XV.) %. (c).	True Manganese in Weld. %. a - (b + c).
(1)	1.05	0.076	0.063	0.91
(2)	0.80	0.04	0.07	0.69

It is thus evident that weld metal laid down by these processes contains very much higher percentages of both silicon and manganese as metals than do the mild-steel welds examined in the main part of the investigation.

It will be noted from Table XV. that the electrode used in process (1) contains a high percentage of manganese (1.92) and this could account for the high manganese in the weld. In process (2) the true manganese in the weld exceeds that contained in the electrode and therefore some manganese is derived from the coating. The high silicon in each case is mainly derived from the flux or coating.

Sulphur prints of the two welds exhibited the pale colour characteristic of mild-steel arc-weld metal discussed earlier.

SUMMARY.

(1) Throughout the summary it is implied that the results refer to the standard conditions employed in the investigation. Six different mild-steel electrodes having coatings of both the iron oxide-silica and the titanium oxide types, with a wide range of potential hydrogen contents, have been examined.

(2) The moisture contents of the various coatings have been determined at two temperatures: 600° and 1200° C. This moisture includes that produced by the combustion of the organic constituents (where present) of the coatings, and it has been found that at least 80% of the water is evolved at 600° C.

(3) The total hydrogen contents of the weld deposits have been determined and, for a given electrode, have been found to be approximately constant and proportional to the total hydrogen available during deposition. In any deposit the total hydrogen can be divided into two portions, one of which escapes slowly at room temperature while the other is apparently held permanently in the metal.

(4) While the total hydrogen in welds made with a given electrode is constant, the proportion evolved in the cold varies considerably; more may be evolved from a weld made with an electrode having a coating with a low total potential hydrogen than from one with a relatively high potential hydrogen. This variability could not be controlled under the conditions of the experiments and no satisfactory explanation has been forthcoming to account for it.

(5) The total oxygen in welds made with a given electrode is constant, but varies from one make of electrode to another. The actual amount appears to depend on the composition (and possibly the amount) of the coating rather than on that of the core wire. The results by the vacuum-fusion and alcoholic iodine methods are in very good agreement.

(6) The composition of the electrode coating has an important influence on the composition of the deposits and on the type of the oxide inclusions.

(a) Oxides of chromium and phosphorus are usually present only in small amounts and can be regarded as accidental impurities.

(b) Small amounts of alumina are found in some of the deposits, but in the present instance its influence can be ignored.

(c) Some of the coatings contain a high proportion of titania, but only a very small amount is retained in the deposits.

(d) The percentage of silica in the deposits varies from 0.044 to 0.122 and according to the X-ray evidence it is present as a silicate of manganese (rhodonite) or iron (fayalite).

Its presence is of importance because by ordinary chemical analysis it is usually calculated to silicon and the properties of the weld metal will depend, to some extent, on the percentage of silicon present. It will be noted that when a correction is made, the deposits examined, with one exception, contain only a very small percentage of elemental silicon.

In one case the percentage of silicon in the weld is greater than

that in the core wire, the extra amount being reduced from the silicate in the coating.

(e) The percentage of oxide of iron in the inclusions varies from 0.004 to 0.20 and the amount presumably depends on a number of factors connected with the composition of the coating and possibly the protective action of the slag formed during welding.

(f) The amount of oxide of manganese in the weld is fairly consistent varying from 0.091 to 0.177%. As in the case of silicon, a correction is necessary to the value for total manganese (by ordinary chemical analysis) in order to obtain the true percentage of elemental manganese. In addition to the correction for manganese oxide allowance must also be made for the percentage of manganese sulphide contained in the weld metal.

(g) The amounts of elemental silicon and manganese in the weld are dependent on the percentages of those elements in the core wire, as well as on the composition of the coating.

(7) In the welds laid down by automatic processes the major constituents of the residue are silica and manganous oxide together with a small amount of ferrous oxide.

The percentages of elemental silicon and manganese in these two welds are much higher than in the welds made with hand-operated electrodes. In one case the manganese can be accounted for mainly by the high percentage contained in the electrode, but the silicon in each case must be derived from the flux or coating.

(8) The principal oxide constituents of each weld (including those by the automatic processes) were identified by means of X-ray examination, and the agreement between the results and those by chemical determination was good. By this means the welds can be divided into two classes, viz., (1) those containing a silicate of the rhodonite type $\text{MnO} \cdot \text{SiO}_2$, and (2) those containing an oxide of the type $(\text{Fe}, \text{Mn})\text{O}$ + a silicate of the fayalite type $2\text{FeO} \cdot \text{SiO}_2$.

In addition, in the former type, manganese sulphide was detected, but there was no evidence of a solid solution of manganese and iron sulphides.

(9) All the deposits showed numerous inclusions, which were mostly too small for detailed examination, but at least three or four types present in each deposit were large enough for identification. It was not possible, however, to correlate the results of chemical and X-ray analysis of the alcoholic iodine residues with these different types of inclusions present.

(10) The appearance of the constituents in the deposits varied with the carbon and nitrogen contents. Except for a shallow surface layer the ferrite grains of all the deposits were very fine.

McQuaid-Ehn tests carried out on three of the deposits showed very abnormal structures. Similar tests carried out on the parent plate material and on the electrodes showed normal structures.

(11) Low-temperature heat-treatment after normalizing resulted in an appreciable reduction in hardness of all deposits except that containing the highest carbon and lowest nitrogen percentage. Microscopical examination after the low-temperature heat-treatment revealed the precipitation of numerous needles, except in the deposits containing the lowest and highest percentages of nitrogen respectively.

(12) All the deposits showed paler sulphur prints than the parent plate material, even when the sulphur contents of the deposits and plate were similar. This effect was observed in other arc-welds but not in oxy-acetylene welds, and is probably due to the much finer state of division of the sulphide particles in the arc-weld deposits as compared with those present in the plate and oxy-acetylene weld deposits.

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REFERENCES.

- (1) W. ANDREWS : *Welding*, 1944, vol. 12, Apr., pp. 186-193; May, pp. 245-248; June, pp. 266-270.
- (2) H. A. SLOMAN : *The Iron and Steel Institute*, 1937, *Special Report No. 16*, pp. 82-100; 1939, *Special Report No. 25*, pp. 43-82; *Journal of The Iron and Steel Institute*, 1941, No. I., pp. 298 P-320 P.
- (3) T. E. ROONEY and OTHERS : *The Iron and Steel Institute*, 1937, *Special Report No. 16*, pp. 109-124; 1939, *Special Report No. 25*, pp. 141-158; *Journal of The Iron and Steel Institute*, 1941, No. I., pp. 344 P-358 P; 1943, No. II., pp. 340 P-350 P.
- (4) L. W. SCHUSTER : *Journal of The Iron and Steel Institute*, 1930, No. II., pp. 249 P-288 P; 1932, No. I., pp. 243 P-283 P.

THE TINNING OF CAST IRON.*

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(Figs. 1 to 13 = Plates XV, to XVIII.)

SYNOPSIS.

The quality of hot-dipped tin coatings on cast iron after different pre-treatments is investigated, using the criteria of continuity of coating, rust resistance, and adhesion. The nature of the bond between tin and cast iron is also studied, by microscopical examination.

The poor tinning quality of cast iron is shown to be caused mainly by the presence of graphite flakes and to be intensified by contamination of the iron surface by graphitic sludge after pickling in acids. Investigation of modifications of the ordinary tinning processes shows that improved tin coatings can be obtained by reducing the duration of pickling in acids to a minimum; this is facilitated by good mechanical cleaning. The best pickling agent is found to be a cold mixture containing 5 vol.-% sulphuric acid and 5 vol.-% hydrofluoric acid. The corrosion-resistance and adhesion of coatings obtained by such modifications of ordinary methods are, however, still low.

Two new methods of preparing cast iron for tinning are described, both involving treatment in molten salts. The chloride method consists of immersing the article in the fused zinc-chloride-sodium-chloride eutectic mixture at 300–350° C., followed by dipping in tin, covered with a layer of the same fused salt mixture, at 300° C. This method gives adherent protective coatings of tin on cast iron which has been well cleaned mechanically. When the cast iron is bonded to white metal, consistent adhesion values of from 2 to 2.8 tons/sq. in. are obtained. The chloride method can be adapted to tinning by wiping.

The nitrate method was developed to give highly adherent coatings of tin and involves the following steps: light pickling in acid to "open up" graphite flakes; immersion for 15 min. at 300–350° C. in fused sodium-nitrate-potassium-nitrate eutectic mixture in order to oxidize surface graphite; pickling in dilute hydrofluoric acid to remove the scale formed in the nitrate bath; fluxing and tinning. Adhesion values of up to 3.8 tons/sq. in. are obtained between tin-base bearing alloy and cast iron tinned by this method. Microscopical examination of the bond shows that the tin penetrates cavities formerly occupied by graphite.

I.—INTRODUCTION.

CAST iron is tinned either to give it a non-toxic, corrosion-resistant coating, typically for food-processing equipment, or to facilitate the adhesion of a white-metal layer, as in bearings. It is well known that cast iron cannot be tinned satisfactorily by the methods commonly used for tinning steel or copper. This is because: (a) Iron castings have a hard skin, containing a high percentage of silicon, graphite, &c., which must be removed before satisfactory tinning can be effected; (b) about 10% of the clean surface area of cast iron is graphite, to which tin does not adhere; (c) pickling acids readily attack the iron, leaving a black film of graphite sludge which is difficult to remove and which prevents effective tinning; (d) owing to the high ratio of weight (heat capacity) to surface area of most iron castings, the tin coating solidifies slowly, with the result that there is ample opportunity for dewetting (retraction of the tin into droplets) to occur.

In view of the difficulty of tinning cast iron directly, it is usual first to deposit electrolytically a coating of pure iron (or occasionally copper), which can afterwards be tinned more readily.

* Received July 24, 1945.

The object of the present research was to evolve methods for hot-tinning cast iron directly, *i.e.*, without the application of an intermediate metal coating. The influence of modifications in the successive stages of cleaning, pickling, fluxing, and tinning was first studied, but it was found later that better tinning was obtained by departing from the above sequence and preparing the cast iron for tinning by treatment in fused salts.

II.—MODIFICATIONS IN THE TRADITIONAL METHODS OF TINNING.

The literature on tinning cast iron is scanty and deals mainly with experience in industry.

The majority of castings intended for tinning fall within the following limits of composition, though over a considerable range the composition of the iron is not important:

Total carbon, %	.	.	.	.	3.2	—3.5
Silicon, %	.	.	.	.	1.7	—2.8
Manganese, %	.	.	.	.	0.5	—0.8
Sulphur, %	.	.	.	.	0.05	—0.12
Phosphorus, %	.	.	.	.	0.6	—1.3

Mechanical cleaning of some kind is essential and may be performed by dry machining, or by sand- or shot-blasting; or the castings may be tumbled in a dry mill with star shot for about 12 hr.,¹ or for about 24 hr. with a mixture of sand and water.²

Graphite may be removed from the surface of the iron by a short decarburizing treatment, in which the iron is heated at 850–950° C. in oxides of iron and manganese for 1–8 hr. This process is used mainly for heavy castings.

Pickling is usually done in hot 5–10 wt.-% sulphuric acid, or in cold 15–100 vol.-% hydrochloric acid, or in 1–5 vol.-% hydrofluoric acid. A mixture of sulphuric and hydrofluoric acid (each 5 vol.-%) is sometimes used.

The next step is often to cover the surface with a thin coating of a metal which is more readily tinned than cast iron. This is generally done by electrodeposition of iron, after which the article must be tinned as soon as possible, as the electrolytic iron rusts quickly. Alternatively, a copper coating may be applied to the cast iron by chemical displacement or electrodeposition, but copper has the disadvantage of dissolving quickly in the tin bath, and contaminates the tin, giving a spangled or a gritty coating. Electroplating with nickel is mentioned by Cymboliste.³

Immediately before tinning, the article is dipped in an aqueous flux containing zinc chloride with or without addition of ammonium chloride.

Either one or two tin pots may be used. The first pot is usually kept at 270–300° C. and covered with zinc chloride or zinc ammonium chloride flux. The second pot is kept between 240° and 260° C. and the surface is covered with tallow or palm oil.

Cast-iron articles are usually of somewhat thick section and therefore retain their heat for a considerable time after removal from the tin pot. If they are cooled in air, excessive draining is likely to occur and oxidation may produce a yellow stain. It is usual to shake off the surplus tin and to quench in oil. Paraffin oil (kerosene) is suitable, provided that it is in sufficient bulk to avoid overheating and risk of fire; it is often floated as a layer on water. Sawdust is generally used for drying and cleaning.

Experimental.

Initial experiments were carried out with flat slabs of grey iron ($4 \times 2 \times \frac{3}{8}$ in.) of known composition, prepared by the British Cast Iron

Research Association. The compositions were chosen so as to provide two silicon contents (1.7 and 2.7%) and two carbon contents (3.0 and 3.5%), phosphorus being constant at 1%. Two different distributions of graphite were provided, fine and coarse. Half the specimens were fully annealed, the remainder being left in the as-cast condition.

Standard Tinning Procedure.

To serve as a standard for comparison and in order to examine the influence of composition and grain-size on tinning quality, a set of slabs was treated by the following sequence, which is afterwards referred to as the "standard procedure."

- (1) Machine (dry).
- (2) Degrease in trichlorethylene vapour.
- (3) Pickle for 20 sec. in 10 wt.-% sulphuric acid at 85° C. (inhibited with 0.5 g. of Stannine per litre).
- (4) Wash in water.
- (5) Dip in aqueous zinc chloride solution (25% of zinc chloride).
- (6) Immerse for 2-3 min. in first tin pot at 300° C., under zinc chloride cover.
- (7) Transfer to second tin bath, covered with palm oil, at 250° C.
- (8) Drain and cool in air.

Although none of the slabs showed any uncoated patches, dewetting was observed to a considerable extent on all the specimens, being greatest in the irons with high silicon and high carbon contents (Fig. 1). By prolonging the pickling, dewetting was accentuated. Grain-size of the graphite had no effect on the appearance of the tin coatings.

Modifications of Procedure.

The effect of modifying the preparation for tinning was examined by treating the iron by one or more of the following processes:

- (a) Shot-blasting.
- (b) Sand-blasting.
- (c) Decarburizing.
- (d) Anodic and cathodic treatments in sodium metasilicate solution.
- (e) Minimum pickling in cold hydrofluoric, sulphuric, or hydrochloric acid or their mixtures.

All of these processes aim at reducing or eliminating the production of graphitic mud, by minimizing the amount of acid pickling required. The results of these tests may be summarized as follows:

(1) *Mechanical Cleaning.*—Machining, grinding, and shot- or sand-blasting give adequate mechanical preparation of the surface before pickling. Sand- or shot-blasting is satisfactory for removing scale after operations such as annealing or decarburizing. Sand-blasting is inferior to the other mechanical cleaning methods, except when followed by hydrofluoric acid pickling; this suggests that silica is left in the surface after sand-blasting.

(2) *Decarburizing* is beneficial provided the scale produced thereby is adequately removed before tinning, preferably by shot-blasting.

(3) *Degreasing by Anodic and Cathodic Treatments in Sodium Metasilicate Solution.*—Short-time anodic or cathodic treatment in cold 10% sodium metasilicate solution, after trichlorethylene degreasing and before light pickling, has a slightly beneficial effect. Coatings produced after such treatments exhibit dewetting, but have a smooth, bright "under-layer" consisting of iron-tin compound with some entangled tin.

(4) *Pickling*.—Before pickling, cast iron should be cleaned mechanically. Pickling then has greater importance as an etching operation than as a means of removing rust. The risk of over-pickling is minimized by pickling in cold acid. The best results were obtained with a cold mixture containing 5 vol.-% of hydrofluoric acid and 5 vol.-% of sulphuric acid (see Fig. 2), or by pickling first in 10% sulphuric acid at 85° C. followed by cold 10% hydrofluoric acid. Pickling solutions listed in decreasing order of merit (2 min. immersion) are:

- (a) A cold mixture containing 5 vol.-% of sulphuric acid and 5 vol.-% of hydrofluoric acid,
- (b) Cold 10 vol.-% hydrofluoric acid,
- (c) Cold 50 vol.-% hydrochloric acid,
- (d) Cold 10 wt.-% sulphuric acid (inhibited with 0.5 g./litre of Stannine),
- (e) 10 wt.-% sulphuric acid at 85° C. (inhibited with 0.5 g./litre of Stannine).

The Effect of Composition and Structure of Iron on Its Tinning Quality.

As a result of the foregoing experiments and other tinning tests, the following conclusions were reached.

The high-silicon, high-carbon irons, when tinned by the standard procedure, gave coatings which were inferior to those obtained on other irons. With improved tinning procedure the differences were not so marked, but it is deemed advisable not to exceed the limits of 3.5% of carbon and 2.7 % of silicon. A high phosphorus content (e.g., 1%) appears to be permissible.

Annealed cast iron was found to have a tinning quality markedly inferior to the as-cast material. Fig. 3 shows the tin coating obtained on a high-silicon, high-carbon annealed iron after tinning by standard procedure (compare with Fig. 1, as-cast). The effect of chemical composition on tinning quality was much more noticeable with the annealed than with the as-cast irons, but the difference can be lessened by an improved technique of preparation, such as by decarburizing followed by shot-blasting and light pickling.

No appreciable influence on tinning quality due to the grain-size of the graphite was observed in the range examined. The fact that the annealed irons, the high-silicon irons, and high-carbon irons (which are all of inferior tinning quality) contain more graphite, supports the hypothesis that the amount of graphite in the iron has a determining influence on tinning quality.

Microscopical Examination.

A microscopical investigation of the cast-iron specimens at successive stages of tinning was undertaken. The specimens, approximately $1 \times 1\frac{1}{2} \times \frac{1}{4}$ in., were ground, degreased, and subjected to the various methods of preparation before tinning. To preserve the prepared surfaces during sectioning and polishing, they were plated with approximately $\frac{1}{16}$ in. of copper. The specimens were mounted in Bakelite and sectioned transversely, to show the boundary between the iron and copper.

Untinned Specimens.

Grinding.—The ground surface of cast iron, examined in this way, was sharply defined and showed no evidence that graphite is smeared over the surface during grinding.

Pickling.—A series of slabs was degreased, immersed for various times in 10 wt.-% sulphuric acid at 85° C. (inhibited with 0.5 g./litre of Stannine), washed in water, copper-plated, and examined as previously described.



FIG. 1.—As Cast. Standard procedure (hot sulphuric acid pickling).

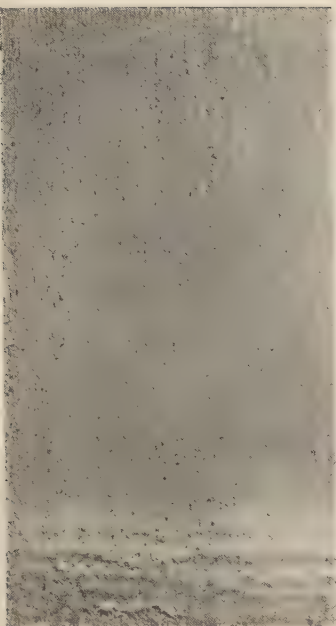


FIG. 2.—As Cast. Tinned after pickling in cold mixed hydrofluoric-sulphuric acid.



FIG. 3.—Annealed (3.5% carbon, 2.7% silicon). Tinned by standard procedure.



FIG. 4.—As Cast. Tinned after treatment in fused zinc and sodium chlorides. Various Procedures. Actual size.



FIG. 5.—Degreased and pickled for 10 min. in 10% H_2SO_4 (inhibited) at $85^\circ C.$, washed in water.

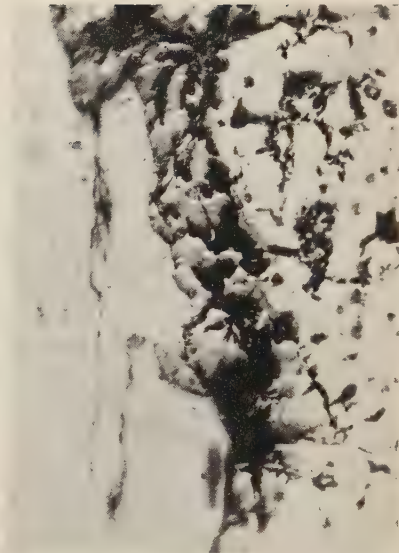


FIG. 6.—Degreased and pickled for 60 min. in 10% HF, washed in water.

FIGS. 5 and 6.—Ground Cast Iron. Unetched. $\times 500$.

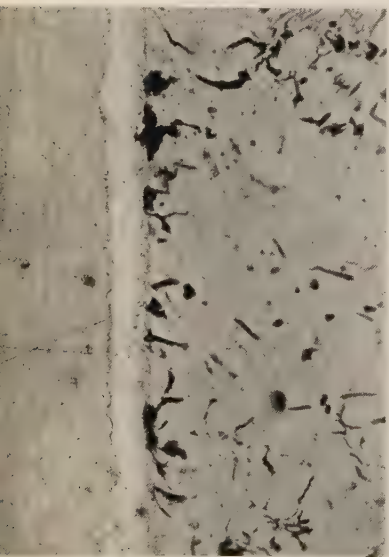


FIG. 7.—Tin bridging over graphite flakes after tinning by the fused-chloride process.



FIG. 8.—Bearing shell, tinned after treatment in the fused-chloride bath and lined with white metal.

FIGS. 7 and 8.—Tinned Cast Iron. Unetched. $\times 500$.

Micrographs reduced to four-fifths linear in reproduction.

[Cresswell.]

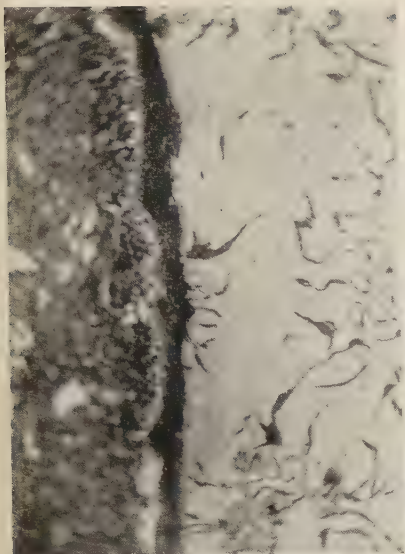


FIG. 9.—Tinned after electroplating with copper.



FIG. 10.—Tinned after electroplating with iron.

FIGS. 9 and 10.—White-Metal-Lined Cast-Iron Bearing Shells. Etched with alcoholic FeCl_3 and 4% picric acid in alcohol. $\times 500$.

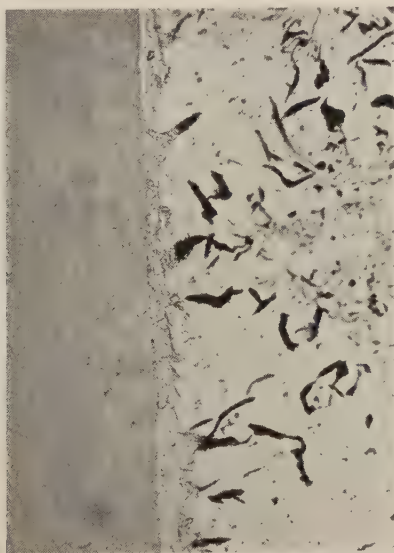


FIG. 11.—Penetration of tin into cavities formerly filled by graphite. (Treated by fused-nitrate method.) Unetched. $\times 500$.

Micrographs reduced to four-fifths linear in reproduction.

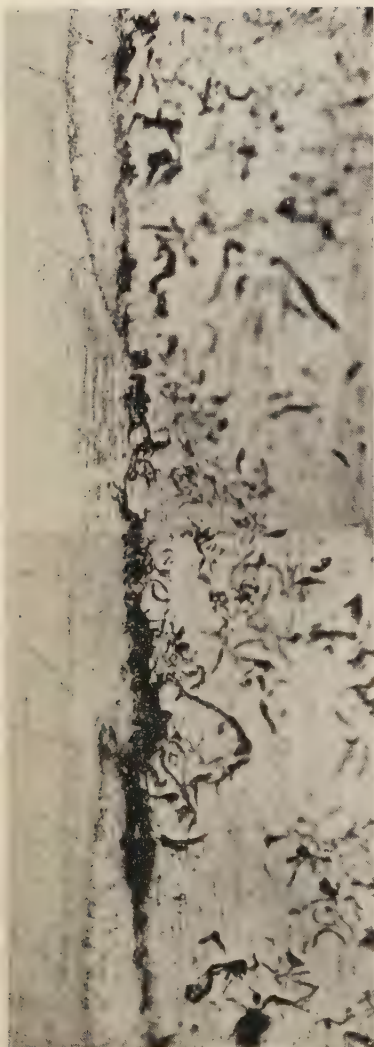


FIG. 12.—Break in Tin Coating on Cast Iron due to graphite outcrop. (Specimen tinned after pickling in hot H_2SO_4 .) Unetched. $\times 300$. Reduced to three-quarters linear in reproduction.

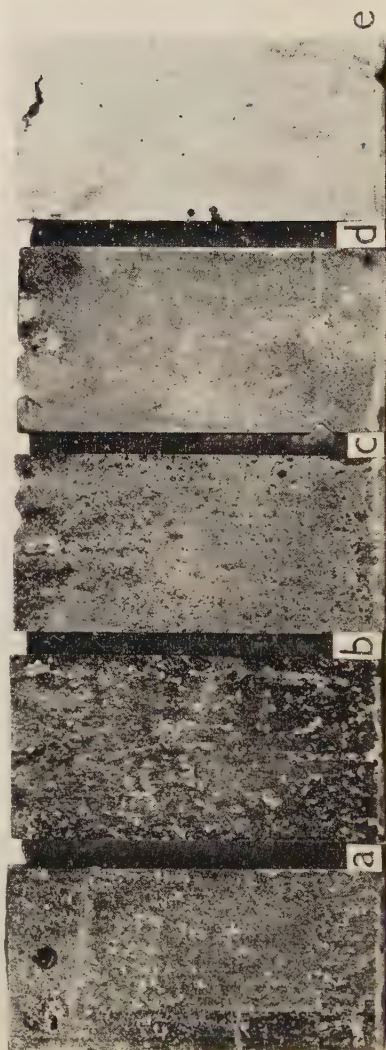


FIG. 13.—Tinned Cast Iron after Hot-Water Porosity Test. (a) Standard tinning procedure. (b) Standard tinning procedure, on annealed specimen. (c) After mixed-acid pickling. (d) After decarburizing and shot-blasting. (e) After treatment in fused-chloride bath. $\times \frac{1}{2}$.

Pickling for 20 sec. produced no appreciable change in the surface of the cast iron; pickling for 60 sec. gave a structure which showed that graphite had been removed from the flakes and deposited on the surface of the iron. This effect was much more marked after pickling for 5 min. The effect of 10 min. pickling is shown in Fig. 5. The specimen showed a number of "plateaux," capped with graphite, and deeply etched portions, which were relatively clean. It appeared that new iron surfaces were being formed by penetration of acid into the graphite flakes, particles of iron thereby becoming isolated and removed.

Pickling for 1 min. in cold 10 vol.-% hydrofluoric acid gave a clean iron surface showing no accumulation of graphite. After pickling for 5 min., a considerable amount of graphite was seen to be spread over the iron surface. When the pickling time was increased to 30 min., there was evidence that the acid had penetrated the graphite flakes and attacked the adjacent iron, leaving some iron as "islands." This feature is shown particularly clearly in Fig. 6 (pickling for 1 hr.). Here it appears that much of the iron has been dissolved and some has been isolated from the main bulk by seepage of the acid into the graphite flakes. What was probably the location of the original surface can be detected as irregular lines in the copper in the left-hand half of the field.

Fluxing.—Fluxing for 30 sec. in aqueous zinc chloride after lightly pickling (20 sec.) in sulphuric acid produced no observable change in the surface of the cast iron.

Tinned Specimens.

In order to facilitate microscopical examination of the tin coatings and the iron-tin interface, the specimens were quenched in paraffin oil immediately after tinning in order to preserve a thick coating of tin.

With all the specimens examined after pickling in sulphuric acid considerable dewetting of the tin coating occurred in spite of quenching. On the surface of the iron there was a considerable amount of graphite. In some cases tin lay over the graphite, but where a large outcrop of graphite occurred, the tin coating was broken. Fig. 12 is a photomicrograph of a break in the tin coating at the site of an outcrop of graphite after pickling in hot sulphuric acid for 20 sec. The tin on the left-hand side of the break partly bridges the graphite. Generally, however, the tin behaved in the manner illustrated on the other side of the break, *i.e.*, with no tendency to bridging. The separation of the tin and iron by accumulation of graphitic sludge is typical of specimens prepared by sulphuric acid pickling.

In general, coatings produced after pickling in hydrofluoric acid were more continuous and showed a greater tendency to bridge over graphite.

Summary.

Improved tin coatings can be obtained by reducing acid pickling to a minimum; this is facilitated by good mechanical cleaning, *e.g.*, machining followed by shot-blasting. Decarburizing is also advantageous if the scale is afterwards removed by shot-blasting. The use of hot sulphuric acid for pickling is not recommended; the best results are obtained using cold acids for as short a time as possible. A cold mixture of sulphuric and hydrofluoric acids (5 vol.-% of sulphuric acid and 5 vol.-% of hydrofluoric acid) proved to be the best pickling agent.

High-silicon irons, high-carbon irons, and particularly annealed irons are of inferior tinning quality, but this is much less noticeable when improved tinning procedures are used (*e.g.*, pickling in cold mixed acids).

The photomicrographs show that as pickling time is increased in either

hot sulphuric or cold hydrofluoric acid a stage is reached where the iron surface becomes contaminated with a considerable amount of graphite, which appears to spread from the graphite flakes. In areas where the graphite covers the surface of the iron, contact between the tin and the iron is prevented and discontinuities in the tin coating result. The tin sometimes bridges over small areas of graphite. The amount of iron-tin compound at the iron-tin interface is small, even when the surface is apparently free from graphite.

Evidence is provided by micro-examination that acids penetrate the graphite flakes and attack the adjacent iron, so that blocks of metal may be partly isolated from the main mass.

The black material which is deposited on the surface of the iron and has been referred to hitherto as graphite, may not consist of graphite alone, but may contain other insoluble material (e.g., silicon). As regards the mechanism by which the graphite reaches and is deposited upon the surface of the iron, it is suggested that during pickling, acid penetrates down the graphite flakes and causes them to swell; the acid also attacks the iron adjacent to the flakes, producing hydrogen, which extrudes the graphite.

III.—THE FUSED-CHLORIDE METHOD.

Treatment of cast iron in fused salts, as an alternative to the processes of degreasing, pickling, and fluxing in aqueous solutions, was investigated with a view to reducing the number of preliminary operations before tinning and also avoiding as far as possible the use of aqueous solutions.

A number of fused-chloride mixtures were found to remove rust from iron and steel at 300–400° C., among which mixtures of zinc chloride, stannous chloride, and sodium chloride were investigated in detail. The best results were obtained with the zinc-chloride-sodium-chloride eutectic (17.8 wt.-% of sodium chloride, melting point 262° C.), which was more fluid at tinning temperatures than the other mixtures and more rapid in its action on the iron.

It was found that immersion of a mechanically cleaned cast-iron article in the fused-chloride mixture could with advantage take the place of degreasing, pickling, and fluxing; the coatings obtained by subsequent dipping in the tin bath were brighter, more uniform, more corrosion-resistant and had better adhesion (see Fig. 4). This method is entirely satisfactory for compact, non-porous castings, the surfaces of which have been adequately prepared by mechanical means, and where good corrosion-resistance and moderate adhesion strength is required. The practical details of operation of this new tinning process are given below.

Practical Procedure.

Mechanical Cleaning.—Machining, grinding, sand- or shot-blasting may be used. Machining or grinding gives the best results.

Stopping-off.—Portions of the surfaces of articles which are required to be stopped-off from tinning (e.g., the backs of bearing shells) are painted with a thin wash containing 25 wt.-% of magnesia, 50 wt.-% of water-glass, and 25 wt.-% of water.

Preheating.—It is desirable to preheat large articles in an oven at 200–250° C. before immersion in the salt bath. To avoid oxidation of the mechanically cleaned surfaces during preheating they are painted over with a solution containing 25 wt.-% of zinc-chloride-sodium-chloride-eutectic mixture.

Salt-Bath Treatment.—The article is immersed in a molten mixture of zinc chloride (82 parts by weight) and sodium chloride (18 parts by weight),

kept in a welded Monel metal container * and heated by Monel-sheathed electric immersion heaters to maintain a temperature of 300–350° C. Owing to cooling, an envelope of solid salt forms on the iron, but this melts after one or two minutes, or more rapidly if the article has been preheated. A suitable time of immersion is 20–40 sec. after the envelope has melted, as detected by moving the article in and out of the bath. The time should not be prolonged beyond that necessary to give a satisfactory coating; over-treatment darkens the surface of the iron and poor tin coatings result.

First Tin Pot.—The articles are transferred to the first tin pot directly from the salt bath. The tin, kept at 300° C., is completely covered with a thin layer of the fused-chloride mixture, which is automatically renewed by carry-over from the fused-salt bath. The duration of immersion should be at least 3–5 min.; longer times (up to 30 min.) give better adhesion.

Second Tin Pot.—This is kept at 240–260° C. and the tin is almost completely covered with palm oil, tallow, or a mineral-base tinning oil. It is employed where a bright and corrosion-resisting tin coating is required, but in many cases (e.g., pre-tinning bearing shells) is unnecessary.

Draining and Cooling.—The articles may be drained and cooled in air, or quenched in paraffin oil. Quenching gives a thicker and more brilliant coating and is necessary with thick sections of iron in order to avoid excessive draining and yellow stain due to oxidation. The quenching bath may consist of a layer of paraffin oil about 2 in. thick on top of cold water. The tinned article is lowered slowly through the oil layer so that the tin solidifies in the oil.

Microscopical Investigation.

Examination after Fused-Salt Treatment.—After suitable preparation, cast-iron specimens were immersed in the fused-chloride bath for different times, washed in water, plated with copper, and sectioned for polishing and microscopical examination.

With times of immersion up to one or two minutes, the surface of the iron was left clean. There was some evidence of removal of graphite from flakes without deposition on the neighbouring iron surface. After immersion for 5 min. the surface showed an accumulation of graphite, resembling that produced by over-pickling in acid. This corresponds with the deterioration of tinning quality and adhesion observed on extending the time of salt-bath treatment to 5 min.

Examination after Tinning.—Cast-iron specimens, after the selected pre-treatment, were tinned, immediately quenched in paraffin oil in order to give as thick a tin coating as possible, and sectioned and prepared for microscopical examination as above.

A section of a coating is shown in Fig. 7. There is no accumulation of graphite sludge between the tin and iron, and the tin is seen to bridge over graphite flakes. This should be compared with Fig. 12, which is typical of specimens prepared by sulphuric acid pickling.

While the main cause of discontinuity of tin coatings on cast iron appears to be the presence of graphite at the surface of the iron, certain other possible causes have also come to light, namely, adhering flux spots and gas evolution from the iron.

In general, the fused-chloride treatment leaves a clean iron surface, which favours contact between the tin and iron over the whole surface, leading to continuous, adherent coatings. Graphite from flakes shows little tendency to spread along the iron surface, in contrast with acid pickling, but after prolonged treatment, there is a tendency for graphite to accumulate at the surface and then the tinning quality deteriorates.

* Cronite also makes a satisfactory container.

Resistance to Corrosion.

Coatings of tin on iron and steel, even when good in appearance, are often discontinuous or porous. These pores form centres of corrosion, from which rusting may subsequently spread over the whole article.

The porosity of the coatings produced by different tinning methods was determined by the hot-water test.⁴ All the specimens tinned after preparation by pickling procedures were very porous, although the porosity was considerably reduced in decarburized and shot-blasted specimens. The coatings produced by the fused-chloride method were remarkably free from pores. The essential features are illustrated in Fig. 13, which is a photograph of some tinned slabs after test. The greatly reduced porosity of the coating produced after treatment in the fused-chloride bath is notable, and the improvements over standard procedure gained by pickling in cold mixed acids (slab c) and decarburizing and shot-blasting (slab d) are also apparent.

Similar results were obtained in outdoor exposure tests.

*Tinning Cast-Iron Shells for Bearings.**Adhesion of a White-Metal Bearing Alloy to Tinned Cast Iron.*

Cast-iron bearing shells are tinned as a preliminary step to lining with white-metal alloys, but trouble is generally experienced owing to lack of adhesion of the white metal to the cast iron, and mechanical keying is usually provided.

Adhesion tests on a series of cast-iron bearing shells tinned by a number of different procedures and lined with a high-grade white-metal bearing alloy (89.5% of tin, 7% of antimony, 3.5% of copper) have been carried out by the technique described by Chalmers.⁵ Three determinations were made on each shell and the results are given in Table I.

TABLE I.—*Adhesion Tests on White-Metal-Lined Cast-Iron Bearings.*

Shell No.	Treatment before Lining.	Adhesion Values, tons/sq. in.			Range of Values, tons/sq. in.
1	Standard tinning.	1.4	0	0	} 0 -1.8
2	"	0	1.8	0.7	
3	Mixed acid pickling and tinning.	0	0	1.1	
4	"	1.8	1.6	X	} 0 -1.8
5	Copper plated and tinned. "	0	0	0	
6	"	1.8	0	2.6	} 0 -2.6
7	Iron plated and tinned.	3.2	2.9	3.1	
8	"	2.9	0.9	X	} 0.9-3.2
9	Electro-tinned (0.0005 in., stannate bath).	0	0	0	
10	Electro-tinned (0.0005 in., acid bath).	0	0	0	} 0
11	Tinned by fused-chloride method.	2.0	2.2	2.3	
12	" " " "	2.5	2.6	2.8	} 2.0-2.8

When 0 is recorded, the lining became detached during sawing or drilling; adhesion is small and indeterminable. When X is recorded, no value could be measured because the lining was forced off by undue strain during sawing or drilling (e.g., jamming of the drill).

The outstanding feature of these results is that adhesion values obtained after preparation for tinning by the fused-chloride method are consistently superior to those obtained by pickling procedures. With acid pickling, the adhesion of the white metal to the iron was often insufficient to withstand sectioning and polishing. The adhesion now obtainable is also

superior to that measured for copper-plated cast iron, in which failure occurs in the plated layer. The only process giving higher adhesion values is the preliminary electrodeposition of iron on the cast-iron surface, which introduces operational disadvantages.

Electroplating with tin appears from these tests to be an unsatisfactory alternative to hot-tinning preparatory to lining cast iron with bearing metal. Before electro-tinning, the shells were machined, degreased, and pickled in cold 75 vol.-% hydrochloric acid, and the possibility remains that other cleaning treatments before electro-tinning might give better results.

Microscopical Examination of the Iron-White-Metal Bond.

Specimens lined with white metal after machining, pickling, and tinning were characterized by the presence of graphite at the iron-white-metal interface and the almost total absence of tin-iron compound.

Machined specimens, treated in the fused-chloride bath, tinned and white-metalled, showed absence of graphite at the white-metal boundary and the presence of a fairly uniform and continuous layer of iron-tin compound (see Fig. 8).

Specimens were examined microscopically after copper-plating, tinning, and white-metalling and after iron-plating, tinning, and white-metalling. With the copper-plated specimen there was a thick continuous compound layer between the copper and the tin (see Fig. 9). With the iron-plated specimen (Fig. 10) the electrodeposit has formed continuously over both the cast-iron and graphite surfaces.

Tinning by Wiping (Modified Chloride Method).

The procedure described below is suitable for tinning objects which are too large to be dipped, such as marine bearing shells, and it also permits the tinning of selected parts of the surfaces of articles, such as insides of large pans, without recourse to extensive stopping-off.

The sequence of operations is as follows:

(1) The surface to be tinned is mechanically prepared by machining, shot-blasting, or sand-blasting.

(2) The surface is brushed with a solution containing 25 wt.-% of zinc-chloride-sodium-chloride eutectic mixture and the article is heated to 270–300° C. The application of aqueous flux effectively prevents oxidation during heating.

(3) An appropriate quantity of previously melted zinc-chloride-sodium-chloride eutectic flux is poured on to the surface at 300° C. and washed over the surface for 1–2 min., the article being rocked gently if possible. To facilitate application of the flux, it is preferable to enclose the area to be tinned so as to constitute a bath. For example, the ends of a large bearing shell may be closed with steel plates.

(4) Any excess of flux is then removed; a quantity of molten tin is poured on to the surface to be tinned, and wiped over the surface by means of steel wire brushes or scrapers. When tinning is complete, excess metal is allowed to drain off and the article allowed to cool, and any flux residues are removed by washing.

The operations of the process should follow one another as quickly as possible. If there is delay between operations (1) and (2) and slight oxidation or rusting has occurred, the tinning surfaces may be brushed over with cold 50% hydrochloric acid or cold 10% hydrofluoric acid immediately before operation (2).

The relatively few adhesion values that have been determined on shells lined by the wiping technique were rather lower than those on shells tinned by the dipping process. This is not surprising in view of the difficulty of control.

IV.—THE FUSED-NITRATE METHOD.

The alternative method of preparation described below was devised with the aim of removing surface graphite flakes from the iron by oxidation before tinning. Two advantages are thus secured: graphite no longer breaks the continuity of the iron-tin boundary layer, and the cavities formerly occupied by graphite can be filled with tin, thus mechanically enhancing bond strength.

Immersion in fused alkali nitrates was found to be a convenient way of oxidising the graphite. The most suitable oxidizing treatment is immersion for 15 min. at 350–400° C. in the fused sodium-nitrate–potassium-nitrate eutectic (51.3% potassium-nitrate, melting point 219° C.). During the treatment the iron is oxidized superficially, acquiring a blue scale which must be removed before tinning can be effected.

The effect on tinning quality of oxidation in fused nitrates followed by various scale-removing treatments has been investigated, the quality of the tin coatings being judged by determination of adhesion and by examination of microstructure.

The microscopical examination confirmed that the fused-nitrate bath removes graphite from flakes at the surface of the iron and also removes the black film which is produced on iron after over-pickling. The tin penetrates into the cavities formerly occupied by the graphite, particularly when these are first opened up by pickling in sulphuric acid (Fig. 11). This gives added mechanical bonding. In a few experiments where preliminary pickling was omitted, the penetration of the tin into the cavities was less complete.

These experiments led to a more detailed examination of tin coatings obtained after various sequences of operations based on the following general principles:

- (a) "Opening up" graphite flakes by pickling.
- (b) Oxidation of graphite by treatment in a fused-nitrate bath.
- (c) Removal of iron oxide scale (produced in the nitrate bath) by acids.
- (d) Removal of silica by hydrofluoric acid. (This also removes iron oxide scale).

Each stage was varied in turn in order to discover the optimum conditions, quality being judged by determination of adhesion and examination of microstructure. During tinning the pot temperature was kept at 300° C., the time of immersion being 5 min. Each specimen was in the form of a bearing shell and, after tinning, was lined with a tin-rich white metal (tin 89.5%, antimony 7%, copper 3.5%) under standardized conditions. A large number of adhesion tests were carried out (six on each shell), and a selection of the results is given in Table II. and discussed below.

In preparing the specimens for micro-examination, sections were made so that three different parts of the specimen could be examined, *viz.*, the iron–white-metal boundary, the fractured bond, and the tinned back of the shell (which was unmachined).

*Discussion of Results.**(a) Variation of the Preliminary Pickle.*

Pickling appears to open out the graphite flakes, thus facilitating oxidation of the graphite by fused nitrate in the next operation and when omitted the adhesion is poor. Moderate pickling also tends to roughen the surface, which mechanically assists adhesion. The best results were obtained by pickling for 30 sec. in hot 10 wt.-% sulphuric acid at 85° C.

TABLE II.—Adhesion Tests of White-Metal-Lined Cast-Iron Bearings Prepared by the Fused-Nitrate Method.

Stages of Tinning Procedure.			Adhesion Values at Various Positions on the Shell, tons/sq. in.						Average Strength, tons/sq. in.	
Specimen No.	Preliminary Pickle.	Oxidizing Bath (KNO ₃ -NaNO ₃ eutectic).	Subsequent Treatment.							
				1.	2.	3.	4.	5.	6.	
1	30 sec. in 10% H ₂ SO ₄ (inhib.) at 85° C.	15 min. at 450° C.	60 sec. in cold 10% HF.	3.8	3.8	3.3	2.9	3.3	2.8	3.3
6	30 sec. in 10% H ₂ SO ₄ (inhib.) at 85° C.	15 min. at 350° C.	As for No. 1.	3.0	2.5*	3.2	3.6	3.0	X	3.2
7	5 min. in cold 10% HF.	As for No. 6.	As for No. 1.	2.4	2.8	2.3†	3.4	2.0†	X	2.9
8	5 min. in cold 5% HF + 5% H ₂ SO ₄ .	As for No. 6.	As for No. 1.	2.6	X	2.3†	2.6	2.8	3.0	2.8
43	10 min. in cold 50% HCl.	15 min. at 350° C.	As for No. 1.	3.0	1.4*	2.6	2.8	3.1	2.8	2.9
9	30 sec. in 10% H ₂ SO ₄ (inhib.) at 85° C.	10 min. at 350° C.	As for No. 1.	1.8	2.5	2.9	2.3	2.1	X	2.3
12	As for No. 9.	15 min. at 300° C.	As for No. 1.	1.3	X	X	2.3	1.7	1.5	1.7
17	As for No. 9.	15 min. at 350° C., but with 5% KHF ₂ added.	As for No. 1.	2.8	2.8	2.6	2.1*	2.6	2.6	2.7
20	As for No. 9.	15 min. at 450° C.	2 min. in cold 50% HCl.	2.1	2.4	1.9	1.9	1.9	2.6	2.1
27	As for No. 9.	15 min. at 350° C.	60 sec. in 10% HF, followed by 30 sec. in fused-chloride bath at 300° C.	3.6	2.7	2.9	3.5	2.6	1.3*	3.0
23	As for No. 9.	As for No. 27.	30 sec. in fused-chloride bath at 300° C.	X	1.6	1.8	0	0	0	<1.7

* Oxide under white metal.

† Hole eccentric.

When 0 is recorded, the lining became detached during sawing or drilling; adhesion is small and indeterminate. When X is recorded, no value could be measured because the lining was forced off by undue strain during sawing or drilling (e.g., jamming of the drill).

(inhibited with 0.5 g./litre of Stannine) or in cold 50 vol.-% hydrochloric acid for 5–30 min. Almost equally good results were obtained by immersion for 5 min. in cold 10 vol.-% hydrofluoric acid or in a cold mixture of 5 vol.-% hydrofluoric acid + 5 vol.-% sulphuric acid. Cold hydrofluoric or hydrofluoric-sulphuric acid has the advantage of removing any silica residues.

(b) *Variation of the Oxidizing Bath.*

It was found that the temperature of the nitrate bath could be reduced from 450° to 350° C. without impairing the quality of tinning, but further reduction of temperature lowered the effectiveness of the treatment. The optimum immersion time for the cast-iron shells used was 15 min.

It was hoped to remove graphite and silica simultaneously from the cast-iron surface by adding hydrofluoric acid (as potassium hydrogen fluoride) to the nitrate bath, but the amounts added (1–5%) did not improve the process.

(c) *Variation of After-Treatment.*

Cold 10 vol.-% hydrofluoric acid is the best agent for removing the scale produced on the iron in the nitrate bath; the fused-chloride bath is less effective.

Practical Procedure.

The article is mechanically cleaned by machining, shot-blasting, or sand-blasting, and degreased in trichlorethylene vapour or a hot alkaline metal-cleaning solution. It is pickled in 10 wt.-% inhibited sulphuric acid (inhibitor : 0.5 g./litre of Stannine) at 85° C. for (say) 30 sec., or in cold 50 vol.-% hydrochloric acid for 2–5 min., rinsed in water, and dried. The article is then immersed in a fused mixture of equal parts by weight of sodium nitrate and potassium nitrate, contained in an ordinary welded-steel or cast-iron pot and heated at 350–400° C. by gas burners or other convenient means. Ordinarily the time of immersion required is 15 min. The treatment oxidizes surface graphite, and produces an oxide film on the surface of the iron. The latter is removed, after washing off excess nitrates with cold water, by further pickling in cold 10 vol.-% hydrofluoric acid for 1 min. After rinsing, the article is fluxed in an aqueous solution of the zinc-chloride-sodium-chloride eutectic and tinned as described for the chloride method.

The nitrate method is capable of producing good tin coatings on all classes of machinable non-alloyed cast irons. The adhesion values are superior to those obtained by using the chloride method, being consistently of the order of 3 tons/sq. in.

From experience with various irons, it appears that the duration of the first pickling treatment must be suited to the particular iron being used. The optimum time must be found by experiment, but it is usually within the range 15–60 sec. when using 10% sulphuric acid at 85° C.

V.—INDUSTRIAL APPLICATIONS : CHOICE OF METHOD.

Both fused-salt methods of tinning have been used successfully on an industrial scale. The fused-nitrate method has been found particularly suitable for tinning small and medium-sized cast-iron bearing shells, where good adhesion is essential. A typical series of adhesion values for a cast-iron shell, tinned by the fused-nitrate method and lined with tin-base bearing alloy under industrial conditions is as follows :

Adhesion Values, tons/sq. in.			
2.5	2.4	2.6	2.2
3.3	2.5	2.4	1.4

The general experience in this laboratory in testing commercial bearings of this type is that the adhesion values normally vary between 0 and 1 ton/sq. in.

The technique for tinning by wiping (modified chloride method) has been successfully tried out on a number of large cast-iron bearing housings for marine engines, Diesel engines, electric generators, &c. For those purposes where appearance is of greater importance than adhesion (*e.g.*, in food-processing equipment, such as mincing machines, saucepans, &c.) the fused-chloride dipping method has proved satisfactory. Both the fused-chloride and fused-nitrate methods have been used for tinning small cast-iron components in order to facilitate subsequent assembly by soldering or sweating.

Where articles or components can conveniently be tinned by total immersion, the nitrate method is the more flexible and reliable, and has the advantage that no special tank or heating equipment is required for the fused salt.

Since no previous pickling treatment is used in the chloride process, a rather higher standard of mechanical cleaning is required than with the nitrate process. A disadvantage of the chloride method is that when tinning porous castings (and porosity is not infrequent) the flux may penetrate deeply into the pores and will not be completely removed in the tinning operation. This may cause sweating of the flux after tinning.

On the whole, the nitrate process is preferred for tinning cast iron by dipping, and the chloride process for tinning by wiping, but the chloride process is satisfactory for dip-tinning when the castings are sound and well-cleaned mechanically.

Either process can be used satisfactorily for coating cast iron with tin-lead alloys by hot-dipping.

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REFERENCES.

1. J. R. SWANTON : *Steel*, 1936, vol. 99, (July 27), p. 40; *Foundry*, 1936, vol. 64, No. 6, p. 26.
2. A. J. T. EYLES : *Mechanical World*, 1926, vol. 80, p. 360.
3. M. CYMBOLISTE, *Fonte*, 1935, No. 18, p. 680.
4. R. KERR : *Journal of the Society of Chemical Industry*, 1942, vol. 61, p. 181.
5. B. CHALMERS : *Journal of the Institute of Metals*, 1942, vol. 68, p. 253.

For Correspondence on this Paper see the *Journal*, 1946, No. 1.

THE DESIGN AND PERFORMANCE OF SOME COMMERCIAL OPTICAL PYROMETERS OF THE DISAPPEARING-FILAMENT TYPE.*

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SYNOPSIS.

A critical examination has been made of five models of commercial portable optical pyrometers of the disappearing-filament type, with reference to the design of the lamp, the optical system, the monochromatic and neutral filters, and the measuring system.

It has been shown that in many cases the lamp filaments are too short to be free from end-effect, and the advantages of the use of a flat-filament in this and other respects are discussed. The size and position of the diaphragms of the optical system were in some examples not in accordance with those necessary for obtaining perfect disappearance of the filament. The transmission curves of the monochromatic and neutral filters are given, and the requirements of the combination of the two filters are examined. A current or voltage calibration of the lamp may be employed and the advantage of the latter for short filaments is pointed out. The potentiometer method used in one pyrometer has considerable merit.

THE disappearing-filament optical pyrometer for use in the research laboratory has been for many years a high-precision instrument. When the design of the optical system is good and due attention has been paid to the choice of the monochromatic screen, the eye can detect a difference of brightness of filament and background of the equivalent of about 2° C., provided that the field is not dark enough to approach the limits of visibility, nor bright enough to produce dazzle. We should, therefore, expect to be able with such an instrument to obtain this accuracy of setting (but not necessarily of temperature measurement) with a single observation, and a considerably higher accuracy than this on the mean of a number of observations. When, however, the pyrometer is manufactured for use in industry, various modifications from the laboratory design are made to make it portable, compact, direct reading, and so on, and these frequently result in a marked falling off in precision. It is the aim of the present investigation to determine how the design of portable pyrometers has deteriorated from that of the high-precision instrument and whether this deterioration were avoidable in view of the function portable units have to fulfil.

For this purpose one of each of five makes of portable pyrometer, of both British and foreign origin, was examined with special reference to the following points of design :

- (1) The pyrometer lamp.
- (2) The optical system.
- (3) The monochromatic and absorption screens.
- (4) The measuring equipment.

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Generally speaking, the findings in the report will be true of any pyrometer of the same model by the same maker, but it should be emphasized that one only of a particular model has been examined and so in some of the particulars a difference of behaviour may be experienced with another instrument. This should not detract in any way from the usefulness of the observations in pointing out the possible defects and showing how these may be eliminated.

I.—THE PYROMETER LAMP.

The first consideration in designing a lamp suitable for use in a disappearing-filament pyrometer is that of the filament size and shape. From every point of view, except, perhaps, ease of manufacture, a flat filament is desirable; the reasons for this will be apparent from what follows and from the discussion on the optical system of the pyrometer. It is general practice to use round-sectioned filaments of diameters lying between 0.04 and 0.06 mm. With diameters of filament much smaller than this there is danger of loss of precision by reason of the smallness of the filament when viewed through the pyrometer; larger diameters are apt to produce error because of the high thermal inertia.

The filament should be sufficiently long to produce a uniform region at the centre of the filament; otherwise the exact point of matching is in doubt and, more important, the lamp calibration will be subject to changes with variations of ambient temperature. For when the centre of the filament is not uniform, its temperature for a given current is no longer solely dependent on radiation losses but partly on conduction losses to the supports. When the temperature of the supports is increased, less current will be required to maintain the same temperature at the centre of the filament. It will be apparent that the end-effect will be most pronounced at the lowest brightnesses; as the brightness is increased the radiation loss becomes greater in proportion to the conduction loss. For similar reasons the time taken for a filament to reach equilibrium on switching on the current, or on changing the current while making a setting, will be greater for a short than for a long filament of the same diameter, and the difference will be more pronounced at the lower brightnesses. In illustration of this point Fig. 1 shows the time taken from

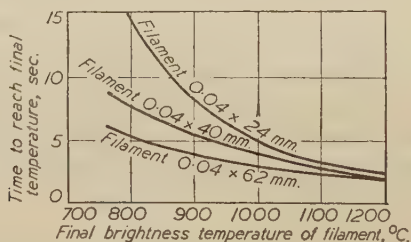


FIG. 1.—Effect of Filament Length on time taken to reach within 2° C. of final temperature.

switching on, for three filaments, each of 0.04 mm. dia., but having lengths of, respectively, 24, 40, and 62 mm., to reach within 2° C. of the final temperature.

Of the pyrometers examined, three had lamps with spherical or conical bulbs and M-shaped filaments all of approximately the same dimensions, namely, dia. 0.06 mm., length 20 mm. One pyrometer had a lamp with a

conical bulb and an inverted V-shaped filament, 0.04×25 mm., and the remaining one a cylindrical bulb with flat windows in the optical path and a straight flat filament of 0.04 mm. width and 25 mm. long. With the exception of the last-mentioned, there was some difficulty in isolating the lamps from their bridge units or other attachments in order to make temperature-coefficient measurements; some results are therefore given in Table I. on a lamp having comparable filament dimensions, namely, 0.06×23 mm. The temperature coefficient in terms of both current-temperature and voltage-temperature calibrations was determined for a change of ambient temperature from 20° to 50° C. In Table I. the coefficient is expressed as the ratio of the change of calibration ($^\circ$ C.) to the change of ambient temperature ($^\circ$ C.).

TABLE I.—*Temperature Coefficients of Pyrometer Lamp.*Filament 0.06×23 mm.

Temp. of Source, $^\circ$ C.	Coefficients.	
	Current-Temp. Calibration.	Voltage-Temp. Calibration.
700	-2.8	-0.2
900	-0.8	0.0
1100	-0.4	+0.1
1300	-0.2	+0.1

We thus have important information on the design of an optical pyrometer. The desirability of using a lamp having a long filament is apparent. For a short filament the temperature coefficient at the lower end of the scale, using a current-temperature calibration, is seen to be quite intolerable, the change in calibration being several times the change in ambient temperature. With such filaments it is much preferable to employ a voltage-temperature relation. Fortunately, in the instruments under inspection, with one exception, the voltage-temperature relation was in use, as three of the instruments employed a bridge unit where, in effect, a voltage measurement obtains, and a fourth had a simple voltmeter across the terminals of the lamp. The exception was in the case of the flat-filament lamp, but the temperature coefficient of this lamp, measured in conjunction with its own pyrometer and measuring equipment, at the lower end of the scale was found to be quite negligible (*see* Table II.). The temperature coefficients of the other instruments, excluding absorption screens and red glasses, were also determined (with the exception of pyrometer *C*, the general condition of which made it impossible to take sufficiently reliable readings). These coefficients, which of course include the temperature coefficients of the indicators, are given in Table II.

TABLE II.—*Temperature Coefficients of Pyrometers.*

Temp. of Source, $^\circ$ C.	A Filament 0.06×20 mm. Bridge Unit.	B Filament 0.06×20 mm. Bridge Unit.	D Filament 0.04×25 mm. Voltmeter.	E* Filament 0.04×25 mm. Potentiometer.
800	+0.1	+0.3 _s	-0.2 _s	-0.0 _s
1000	+0.1 _s	+0.3 _s	-0.2 ₇	...
1200	+0.1 _s	+0.2 _s	-0.3 ₁	...

* Coefficient of lamp only; filament flat.

It is of interest to note that a cylindrical filament of the same diameter as the width of the flat filament quoted above, namely 0.04 mm., and a comparable length, 24 mm., had, under the same conditions, a current-temperature coefficient of -0.6 , thus demonstrating one of the advantages of the flat over the cylindrical filament.

As already mentioned, another aspect of the problem of filament size is the time taken for thermal equilibrium to be established on switching on the current. This is particularly important where it is necessary to take rapid readings. Two of the pyrometers had a spring contact for switching on the current, to be operated by the observer's hand as the setting was made, and thus readings might be taken before thermal equilibrium is established. This could hardly happen with a long filament; a filament of 0.06 mm. dia. and long enough to be free of end-effect reaches to within 2°C . of its final temperature in about 2 sec. on switching on from cold. If the filament is short, however, an appreciable time is taken for the final temperature to be reached. Fig. 2 shows the change of

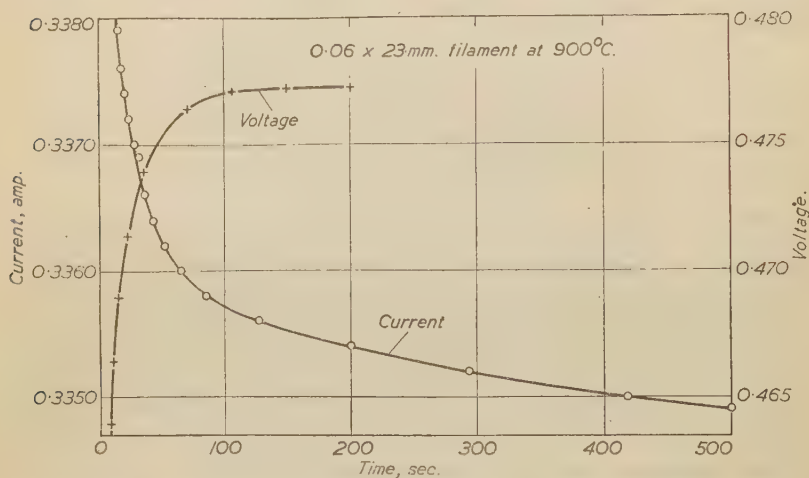


FIG. 2.—Change of Current and Voltage with time from switching on. (Short filament.)

current and voltage, for a short filament, with time from first switching on. Fig. 3 shows the time from switching on required by the same filament to reach within 2°C . of its final temperature.

As an example of the magnitude of the error which may result from this effect, sets of observations on a pyrometer having a spring contact switch are given in Table III. The readings in the first column were obtained by depressing the switch and taking observations in quick succession, say at intervals of 5–10 sec., with the switch continuously depressed, and those in the second column when the switch was held down for an appreciable time before readings were started.

The second pyrometer in which a press contact switch was provided was that in which the lamp had a flat filament and here the thermal inertia was negligibly small. This is a further advantage of the flat over the cylindrical filament. Other advantages are that for a flat filament equal in width to the diameter of a cylindrical filament, the current consumption is considerably smaller and, as will be seen in the discussion on the optical

system of the pyrometer, wider entrance and exit angles may be used for perfect disappearance of the filament, thus giving a brighter field.

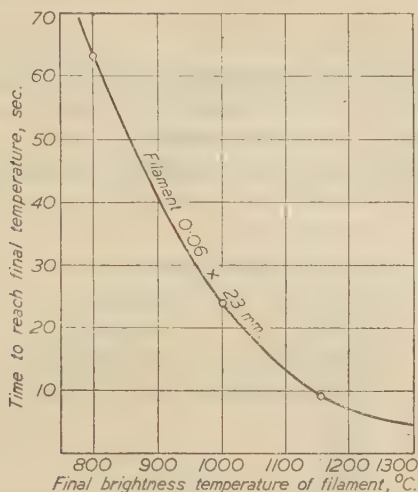


FIG. 3. Time Taken by Short Filament to reach within 2° C. of final temperature. (Same filament as in Fig. 2.)

TABLE III.—Pyrometer Readings Showing Error Due to Thermal Inertia.

Filament 0.06×20 mm.

Before Filament reaches Equilibrium, ° C.	After Filament Stabilized, ° C.
1000	1010
1003	1010
1004	1010
1006	1010
1008	1010
1008	1010

II.—THE OPTICAL SYSTEM.

The optical system of the disappearing-filament pyrometer consists of a telescope in which the lamp filament is situated in the image plane of the objective, and the image of the source, superimposed on the filament, is viewed by the eye-piece. The objective lens must be of appropriate focal length to the purpose of the pyrometer and should be an achromat if work without using the red glass screen is contemplated. For commercial pyrometers a single lens is generally quite satisfactory. The eye-piece lens or combination of lenses should give a magnification sufficiently high to make adequate use of the resolving power of the system. This point is explained in what follows. It has been shown* that, unless the values of entrance and exit angles (α and β in Fig. 4) of the telescope

* Fairchild and Hoover: *Journal of the Optical Society of America*, 1923, vol. 7, p. 543.

for a given diameter of filament lie between certain limits, provided that the resolving and magnifying powers of the eye-piece are sufficiently high, complete disappearance of the filament is not possible; disappearance may be obtained for angles outside these limits if the resolving power is low, but this results in a loss of precision. The non-disappearance of the filament is caused by diffraction and, in the case of cylindrical filaments, reflection of light at the edges of the filament. For flat filaments the effect is due to diffraction alone. As a result the filament appears edged by bright and dark bands.

The values of entrance and exit angles necessary to obtain good disappearance have been worked out by Fairchild and Hoover (*loc. cit.*) and are shown in Table IV.

TABLE IV.—*Entrance and Exit Angles of Telescope for Disappearance of Filament.*

Exit Angle, radian.	Min. Entrance Angle, radian.
<i>Flat Filaments (any width).</i>	
0.02	0.07
0.03	0.10
0.04	0.13
0.06	0.17
0.08	0.21
0.10	0.23
0.12	0.25
<i>Cylindrical Filaments (dia. 0.04–0.06 mm.).</i>	
0.04	0.08–0.13
0.02	0.06–0.16
0.01	0.04 and larger

The table shows that much larger angles can be tolerated for flat than for cylindrical filaments, with the advantage of more light being available; this is of considerable importance at the lower brightnesses. For cylindrical filaments there is a greater tolerance in the value of the entrance angle as the exit angle is reduced.

In calculating the best dimensions of stops and the eye-piece requirements, the starting point is the filament of the lamp. For a filament of dia. 0.04–0.06 mm., Table IV. shows that the maximum size of the exit angle is 0.04 radian, and the entrance angle should be between 0.08 and 0.13 radian. The size of the exit angle determines the resolving power of the eye-piece. With red light ($\lambda = 0.6 \mu$) this resolving power has a value of 0.015 mm. and, taking the resolving power of the eye as $\frac{1}{3000}$, it will be seen that the magnification of the eye-piece should be at least 6 and preferably about 10 in order to obtain the maximum acuity of vision.

Fig. 4 shows the essential features of the optical systems of the five pyrometers. On each diagram is given the values of the entrance and exit angles, α and β , and the magnification. Referring to Fig. 4(a), it is observed that the values of α and β do not conform to the above-stated requirements, β being far too large. Disappearance of the filament is obtained, however, since the magnification is not sufficiently high to resolve the defects of image. There is thus a loss of precision.

In Fig. 4(b), both entrance and exit angles are far too large. Since in this case the magnification is large enough to give sufficient acuity of vision, the edging of the filament is visible. The diaphragm *AB* is not

a limiting diaphragm on the entrance cone of radiation, which thus varies with the focal distance of the objective.

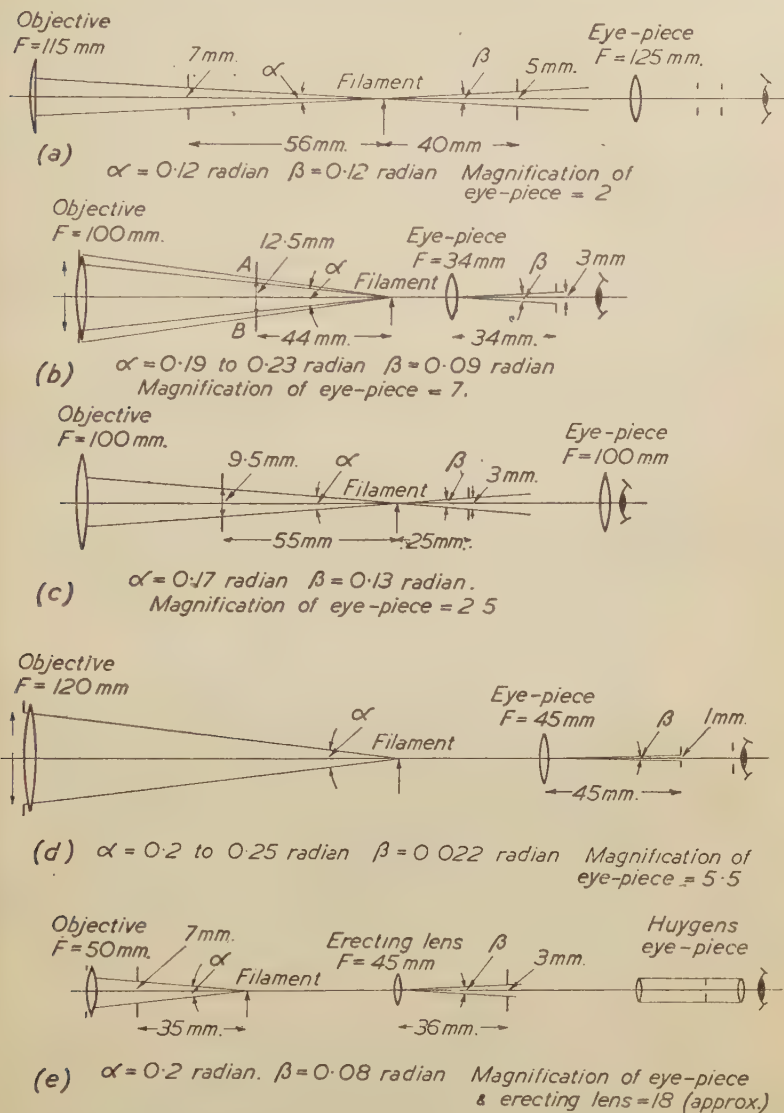


FIG. 4.—Optical Systems of the Five Pyrometers Examined.

The third example, Fig. 4(c), suffers from the same defect of incorrect diaphragming; both angles are too large. The magnification is too low to take advantage of the resolving power and so disappearance is obtained

at the expense of precision in matching. The optical system here suffers also from a further defect in that there is no pupil diaphragm fitted.

In Fig. 4(d), the resolving power of the ocular is only 0.03 mm. and, although the magnification is sufficient, this is not high enough to detect the edging of the filament. Thus disappearance is obtained by excessive reduction of the resolving power. No limiting diaphragm on the entrance cone of radiation is provided.

In Fig. 4(e), the angles α and β are seen to conform with those specified in Table IV. for flat filaments. The resolving power in this arrangement, 0.008 mm., is seen to be twice the maximum attainable, 0.015 mm., for the cylindrical filaments. The magnification of the eye-piece is quite adequate to take full account of this resolving power and so high precision of matching is obtained. Under the correct conditions for perfect disappearance of the filament with adequate resolving power and magnification, a brighter field is obtained by reason of the larger angles permissible. It is observed that high magnification of the eye-piece is here obtained by the use of a Huygens eye-piece, with the consequent advantage of a much improved image.

Attention has been drawn in the above comments to the absence of a limiting diaphragm between the objective and the filament in two examples. Although, for perfect disappearance under the best conditions, it is necessary to have a diaphragm in this position fixed relative to the filament, it is not generally the limiting diaphragm of the system, this being determined by the eye-piece diaphragm. The cone of radiation entering the eye is therefore constant for different positions of the objective. In the case of cylindrical filaments, however, the brightness of the filament is slightly affected by reflection of incident light at the edges of the filament, and variation of the entrance cone will thus produce a very slight variation in the apparent brightness of the filament. It would, therefore, apart from the reasons of good disappearance, be more satisfactory to have a diaphragm to keep the entrance angle of the telescope fixed.

It will be noted that in Fig. 4(d) and (e), the exit diaphragm is placed between the eye-piece lens and the eye, approximately at the focus of the lens. This arrangement is to be preferred to others, in which this diaphragm is between the filament and the lens, since a wider field of view is obtained with greater uniformity of illumination. The larger field of view adds considerably to the ease of sighting on the object.

In the five examples given of the optical systems in use we thus see that in one only, the fifth, are ideal conditions for good disappearance of the filament attained. The large angles are presumably adopted in order to have sufficient field brightness at the lower end of the scale. The problem may be dealt with, as in Fig. 4(e) by the use of a flat filament, or, where cylindrical filaments are employed, by the complete removal of the red glass screen for temperatures of the source below 800° C. The effect of this on the accuracy of the temperature measurements is discussed in the next section.

III.—THE MONOCHROMATIC AND ABSORPTION SCREENS.

A disappearing-filament optical pyrometer may be operated quite satisfactorily at low intensities, 650–1000° C., without using a colour screen. Provided the calibration has been carried out for black-body radiation and temperature measurement is made on a black body, no error will result. If measurement is made on a non-black body, the wave-length to which the temperature is to be ascribed must be specified, in this case the Crova wave-length. It is found that at temperatures higher than 1000° C. a difference of colour between the tungsten filament

of the lamp and the black-body source becomes apparent, and so complete disappearance of the filament cannot be achieved. Thus it is necessary, in order to eliminate this colour difference and also to define the effective wave-length more precisely, to limit the wave-band of light used. This would be most satisfactorily achieved, were it not for the small quantity of light consequently available, by the use of strictly monochromatic light, such as given by a spectroscope, for no matter what the spectral distribution of the source as compared with that of the filament, satisfactory matching of both brightness and colour could always be obtained. It has been shown, however, that satisfactory results can be achieved by the use of a carefully chosen so-called monochromatic glass screen, with the additional advantage of far greater luminosity; this is one of the more important reasons for selecting a red glass screen for this purpose. The red glass employed in an optical pyrometer usually has a wave-length cut-off on the short wave-length side at about 0.61μ and a steep rise in transmission to 80-90% in the region $0.65-0.75\mu$ and beyond. The limit of visibility of the eye is at about 0.70μ , rising to some 55% at 0.60μ and thus the effective band of light lies between 0.60 and 0.70μ , with a sharp maximum in the region $0.64-0.65\mu$.

For temperature measurements on a black body without an absorption screen, it is not necessary to know any more about the red screen than that sufficient sensitivity and reproducibility of reading are obtainable. If, however, a non-black-body source is used, it is important to know the wave-length employed in the pyrometer, for the brightness of such a source, relative to that of a black body at the same temperature, varies with the wave-length. In other words the apparent, or black-body, temperature of the source is a function of the wave-length. It may be shown that, if T_1 is the black-body temperature of the source for a wave-length λ_1 , and T_2 that for a wave-length λ_2 then :

$$\frac{1}{T_2} = \frac{\lambda_2 - \lambda_1}{\lambda_1} \left(\frac{1}{T_1} - \frac{1}{T_0} \right) + \frac{1}{T_1} \quad \dots \dots \dots (1)$$

where T_0 is the colour temperature of the source. Since, as indicated above, the wave-band operative has finite width, it is necessary to determine the effective wave-length, which is defined as follows. If E_1 is the energy radiated by a black body at a temperature T_1 , and E_2 that at a temperature T_2 , then the wave-length must be so chosen as to give :

$$R = \frac{E_1}{E_2} = \frac{L_1}{L_2},$$

where L_1 and L_2 are the corresponding luminosities through the screen in question. From Wien's law :

$$\begin{aligned} \log R &= \frac{C_2}{\lambda} \left(\frac{1}{T_1} - \frac{1}{T_2} \right) = \log \frac{L_1}{L_2} \\ \therefore \lambda_0 &= \frac{C_2 \left(\frac{1}{T_1} - \frac{1}{T_2} \right)}{\log \frac{L_1}{L_2}} \end{aligned}$$

for the interval T_1 to T_2 .
Since :

$$L = \int_0^{\infty} E_{\lambda T} V_{\lambda} t_{\lambda} d\lambda,$$

where V = the visibility function of the eye and t = the transmission of the monochromatic screen, in the limit when T_2 approaches T_1 :

$$\lambda_T = \frac{\int_0^\infty E_{\lambda T} V_{\lambda} t_{\lambda} d\lambda^*}{\int_0^\infty E_{\lambda T} \frac{1}{\lambda} V_{\lambda}' d\lambda}$$

which is known as the limiting effective wave-length.

It is also necessary to know the effective wave-length of the red glass, if it is required to extrapolate the scale by means of an absorption device

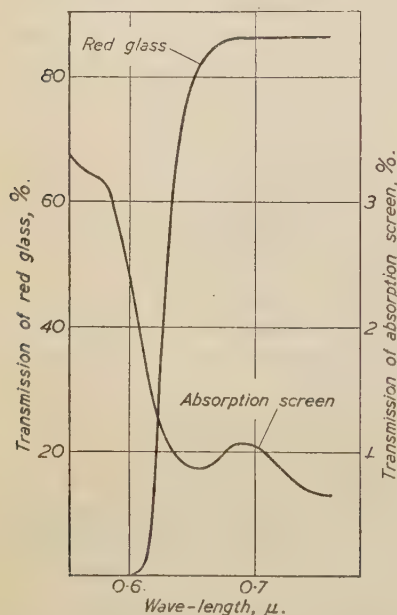


FIG. 5.—Pyrometer A. Glass thickness, 4.01 mm.; screen thickness, 2.44 mm.; $\lambda = 0.647$.

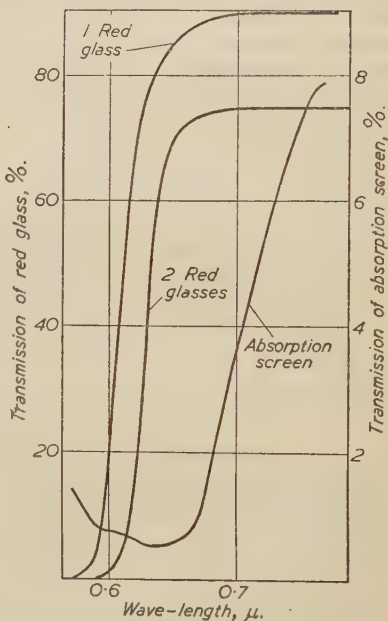


FIG. 6.—Pyrometer B. With one glass $\lambda = 0.634$; with two glasses $\lambda = 0.647$. Screen thickness, 1.23 mm.

such as a rotating sector or absorption glass. From Wien's law the temperature interval for a transmission factor, R , of the absorption device is given by:

$$\frac{1}{T_1} - \frac{1}{T_2} = \frac{\lambda \log R}{C_2} \quad \dots \dots \dots (2)$$

When an absorption device is interposed between the filament and the source, the red glass must be chosen with greater care than formerly in order to ensure good colour matching. This is on account of the difference of the energy-wave-length distribution at the two temperatures, and thus although the intensity of the source may be reduced by the absorption device to that of the filament it does not produce the same colour. The colour difference will obviously be greater the smaller the

* Foote: U.S. Bureau of Standards Bulletin, 1916, vol. 12, p. 484.

transmission factor. Conditions become even more stringent when the absorption screen is appreciably selective. Where the screen transmits more on the short than on the long wave-length side of the band, it may be necessary to use a deeper red glass; if the reverse is the case it may not be possible to eliminate the colour difference without introducing an additional screen to cut off on the long wave-length side of the band.

It will be realized that if a pyrometer is calibrated over its whole range by comparison with a standard pyrometer or source, such as a tungsten-strip lamp, the neutrality, as such, of the absorption screen is not important, provided that the colour matching of the filament against the background is satisfactory. The effective wave-lengths of the two

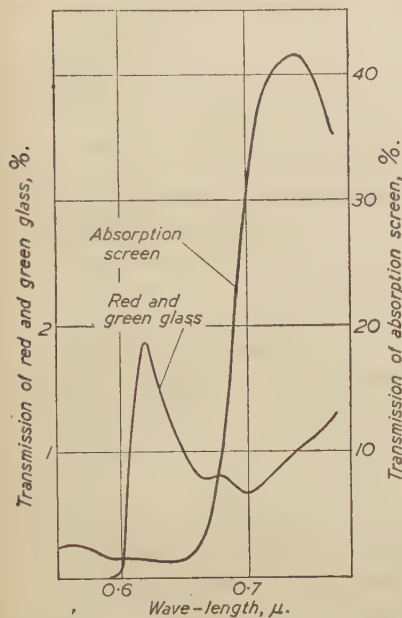


FIG. 7.—Pyrometer C. Combined glass thickness, 4.04 mm.; screen thickness, 2.98 mm.; $\lambda = 0.626$.

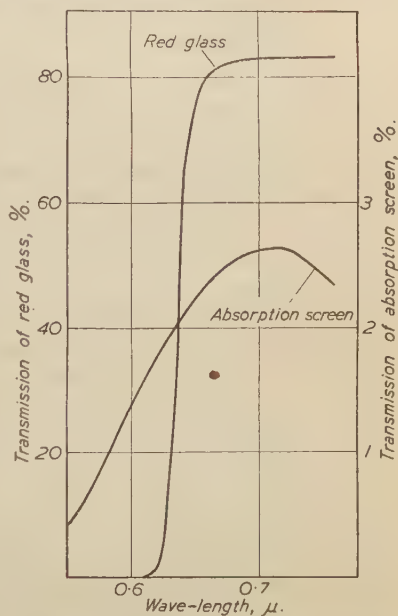


FIG. 8.—Pyrometer D. Glass thickness, 2.06 mm.; screen thickness, 1.29 mm.; $\lambda = 0.648$.

FIGS. 5 to 8.—Transmissions of Red Glass and Absorption Screen for Pyrometers A to D.

pyrometers being compared should be the same or, if they differ, a correction should be applied as indicated above.

To recapitulate, the requirements of the red glass and the absorption screen are as follows :

- (1) *With no absorption screen and a black-body source :*
The red glass needs only to give a good colour match.
- (2) *With no absorption screen and a non-black-body source :*

The wave-length of the red glass must be known, since the brightness relative to a black body is a function of the wave-length.

(3) *When an absorption screen* is used :*

(a) The combination of red glass and absorption screen must give a good colour match.

(b) *Non-black-body source.*—The wave-length of the red glass must be known, for the same reasons as given in (2) above.

(c) *Extrapolation by means of the absorption constant.*—The absorption constant depends on the wave-length of the red glass and this should therefore be known. Strict neutrality of the absorption screen is desirable over the relevant wave-band.

(d) *Calibration by comparison with a standard pyrometer or source.*—The neutrality of the absorption screen is not important, provided that conditions 3(a) and 3(b) are taken into consideration.

In order to determine how nearly the above-stated requirements were satisfied in the pyrometers examined, the transmissions of the red glasses and absorption screens were measured; * the curves are given in Figs. 5 to 9. On each curve is given the effective wave-length of the red glass for a brightness temperature of the source of 1600°C . The range of wave-lengths is $0.626\text{--}0.655\mu$ and this represents a difference of 6°C . in the black-body temperature of a tungsten source at 1600°C . In the case of pyrometer *A* (Fig. 5) there was a lack of colour match, and this may be attributed to the use with the absorption screen employed of a red glass transmitting too far into the short wave-length end of the band. Thus, if a red glass having a transmission comparable with that of pyrometer *E* is employed, the colour difference is eliminated. Pyrometer *C* had a combination of red and green glass screens, giving a transmission as shown in Fig. 7. The two components were placed sufficiently close together to produce interference fringes, and the transmission would thus vary with the part of the screen employed. The transmission of this combination is seen to be much lower than with the other screens, resulting in an unnecessary loss of light, whilst the effective wave-length is very much lower than is usually obtained; consequently care is needed in applying the necessary correction when comparisons are made with other pyrometers sighting on a non-black-body source. Obviously the absorption screen used here is unsuitable, on account of the very sharp rise in transmission towards the long wave-length end of the band. Thus, at 0.65μ the transmission is 2.4% and at 0.7μ , 32%. The use of any of the red glasses here discussed with this absorption screen would not eliminate colour difference; hence the addition of the green glass above-mentioned. In the case of pyrometer *B* there is also a rise in transmission of the absorption screen between 0.67 and 0.70μ , but this rise is not of the same order as in the previous example, being only from 1 to 3.6%, and this is apparently insufficient to produce any appreciable colour difference with the type of red glasses usually employed. In connection with the curves given for the red glasses in this instance, only very approximate measurements were possible on account of the extremely small area of glass available. The absorption screen of pyrometer *D* has also an appreciable slope in the same direction as in the two previous cases, from $5\frac{1}{2}\%$ at 0.62μ to $10\frac{1}{2}\%$ at 0.7μ , but no colour difference is here produced; however, the transmission of this glass is much greater than those of the other glasses, being about 6% (compared with between 1 and 2%), thus making conditions more favourable to good colour matching. The red glass and absorption screen combination employed in pyrometer *E* pro-

* These measurements were made by the Light Division of the National Physical Laboratory.

duced good colour matching, but it should be noted that the maximum scale reading in this pyrometer was 1750° C.

It has been mentioned that it is advantageous to have a combination of red glass and absorption screen which gives a constant value to the absorption factor :

$$K = \frac{1}{T_1} - \frac{1}{T_2} = \frac{\lambda \log R}{c_s},$$

no matter what the value of the temperature of the source. If this is achieved, extrapolation by means of such a combination may be carried out with greater accuracy. The calibration of the pyrometer also becomes a very much simpler matter, as a single determination of this constant suffices to fix the complete high range of the pyrometer by reference to the first range. In illustration of this point the values of transmission factors and absorption constants for pyrometers *A* and *E* over the high-temperature range of the instruments are given in Figs. 10 and 11. The variation of the absorption constant with temperature of the source for pyrometer *E* is negligible. Evidently in this case some importance has been attached to the necessity for producing an invariable absorption constant. In each of these cases the factors have been calculated from the transmission curves of the absorption screens in conjunction with the appropriate red glass transmissions and the effective wave-lengths applying to the temperature intervals produced by the absorption screens.

The effect of the change of air temperature on the pyrometer reading due to changes in the transmission of the absorption screen was measured by separating the absorption screen from the pyrometer, placing it between the objective and the source, and heating it to 50° C. A rise of about 30° C. in the ambient temperature in no case produced a greater change than about 3° C. in the reading, at a source brightness of 1600° C.; this gives a coefficient of 0.1, which is quite negligible for most practical purposes. The transmission of the glass becomes less as the temperature rises, and in general the change is greater the steeper the slope of the transmission-wave-length curve. This, then, is an additional reason for using, for high precision, an absorption screen as strictly neutral as is possible.

The temperature coefficients of the red glasses were not measured, since they are not likely to be sufficiently great to be of importance in the accuracy of measurement with which we are here concerned. Measurements have been made on various red glasses and these show that the transmission curve moves towards the long wave-length end of the spec-

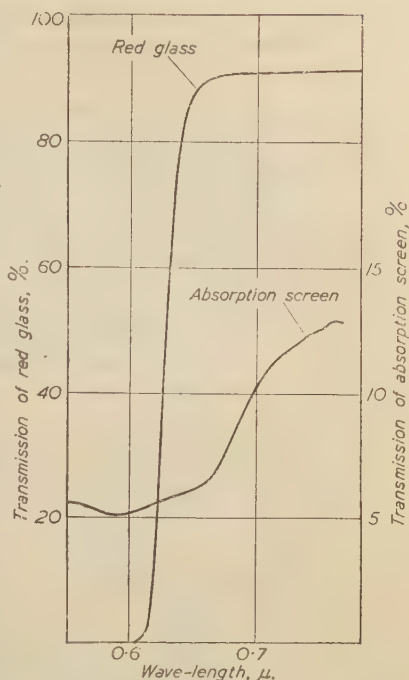


FIG. 9.—Transmissions of Red Glass and Absorption Screen of Pyrometer *E*. Glass thickness, 2.82 mm.; screen thickness, 3.34 mm.; $\lambda = 0.655$.

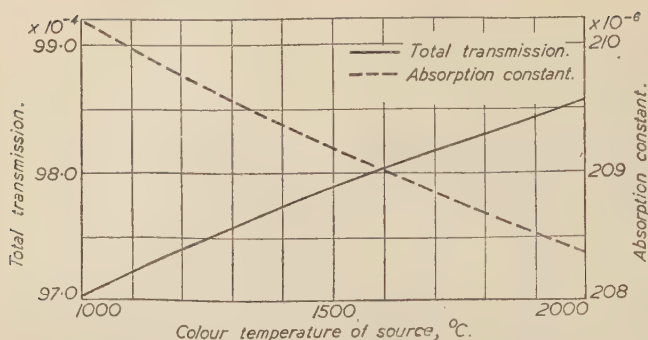


FIG. 10.—Pyrometer A.

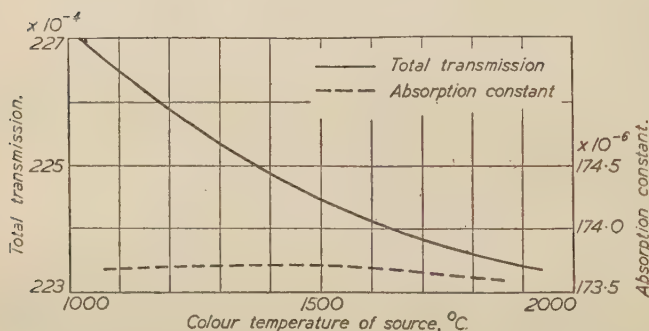


FIG. 11.—Pyrometer B.

FIGS. 10 and 11.—Transmission Factors and Absorption Constants over High-Temperature Range.

trum as the temperature is increased. The change amounts to about 0.001μ in effective wave-length for 10°C. change of temperature; at a source temperature of 1600°C. this is equivalent to about 1°C. when an absorption screen giving a reduction of 0.01 is employed.

IV.—THE MEASURING EQUIPMENT.

It has been mentioned previously that the pyrometer may be calibrated in terms of current or of voltage, and the advantage of the latter method has been explained. Where the lamp filament is sufficiently long to be free of end-effect, current measurement, for well-known reasons, is to be preferred. For precision work the current is determined by measuring the potential drop on a standard resistance in series with the lamp, by means of a potentiometer. With the commercial pyrometer, in the interests of compactness and portability, it is customary to use an ammeter or voltmeter. In either case a simple circuit has certain disadvantages, the chief of which is that the full scale of the instrument cannot be usefully employed without some device for setting back the zero; otherwise the point at which the filament becomes visible is when the ammeter or voltmeter needle is some half-way up the scale. Thus the scale becomes very cramped and there is a loss of accuracy of reading. The most satisfactory

method adopted for overcoming this difficulty is to make the lamp one arm of a Wheatstone bridge. The bridge is balanced for the lowest temperature to be measured, and thus the full scale of the galvanometer may be employed.

Three of the pyrometers under review had such bridge systems. Two of these had the circuit design, due to Schofield and Gall * shown in Fig. 12(a). A new lamp may be inserted in this system without recalibrating the scale of the millivoltmeter, an important consideration in an industrial pyrometer. This is achieved by breaking the bridge circuit at the points marked *a*, *b*, *c*, and *d*, and inserting the new lamp complete with the resistances *P*, *R*, and *S*, adjusted to suit the calibration of the new lamp. It will be observed that a change of contact resistance at the points *a* and *c* is without effect upon the calibration. At *b* and *d* the change will, in general, be small compared with the total resistance of the arm. The third pyrometer used the bridge system shown in Fig. 12(b),

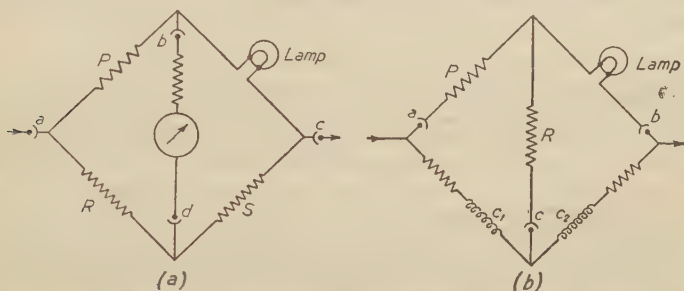


FIG. 12.—Circuit Design (a) in two of the bridge-system pyrometers and (b) in third bridge-system pyrometer.

where C_1 and C_2 are the coils of the differential galvanometer employed. Here the change of lamp is made by breaking the circuit at the points marked *a*, *b*, and *c* and replacing the resistances *P* and *R*. The contact resistances *a* and *b* are in the low-resistance arms (about 2 ohms) of the bridge and a change in their values would cause significant errors.

Another of the pyrometers had a simple voltmeter across the lamp and suffered, therefore, from the disadvantage of the cramped scale.

All four pyrometers so far discussed in this section were in one unit, the indicator being mounted on the telescope, and the question of the balance of the indicator movement thus becomes one of major importance. One only of these indicators showed a serious change of reading with position, a difference of 10° C. on the first scale being observed between the vertical and horizontal positions of the telescope. In one case, too, a marked "stickiness" of the movement was noted; the reading sometimes changed by about 5° C. on the first scale on tapping the indicator after making a setting.

From Table II. it will be observed that the temperature coefficient of the indicator, allowance being made for that of the lamp, may be as high as 0.25. Thus a substantial difference of reading may result from a change of ambient temperature of 10° C., being about $2-3^\circ$ C. in the low range and about twice this amount on the high range of the pyrometer.

The remaining instrument had a separate portable potentiometer and in effect employed a current-temperature calibration, in contrast to all the other instruments (which used a voltage-temperature relation). It

* *Journal of Scientific Instruments*, 1924, vol. 1, p. 193.

has been shown (Table II.) that the pyrometer lamp in this case has a negligible end-effect. The potentiometer system has important advantages over the other methods. The potentiometer galvanometer is a null instrument and therefore the changes due to position temperature coefficient, alteration of magnetic field or control are not of importance. Thus a relatively high-sensitivity galvanometer may be employed and a very open scale calibration obtained by the use of a long slide-wire. In this way the uncertainty of reading the scale is eliminated. Of course the instrument is not so compact as the others and two operations are required, one in making the brightness match, and the other in balancing the potentiometer, but the design is such that both may be rapidly carried out.

V.—CONCLUSIONS.

This section summarizes the conclusions to be drawn from the foregoing and also discusses a few additional points of design not already mentioned.

(1) *The Lamp Filament.*

The lamp filaments in four out of the five instruments examined are too short in relation to their diameters to give high-precision readings. Such short filaments are subject to temperature-coefficient and thermal-inertia errors. The temperature coefficient is shown to be less for a voltage-temperature than for a current-temperature calibration. The former system of measurement is employed in these four instruments and the coefficient for a filament of equivalent size to those in use is shown to be of the order of 1°C. on the low range of the pyrometer, for a change of air temperature of 10°C. The error on the high range would be of the order of twice this amount. The thermal-inertia effect becomes most serious when the reading is taken immediately after switching on the current. Thus with one of the pyrometers, a reading taken some 20 sec. after switching on, at a scale reading of 1000°C. , was about 8°C. lower than the reading when thermal equilibrium had been reached. In order to be free of these effects the minimum length of a filament should be 60 mm. for a dia. of 0.06 mm., and 50 mm. for a dia. of 0.04 mm. The flat filament has been shown to be superior to the cylindrical filament in both respects.

(2) *The Optical System.*

In only one of the pyrometers were the entrance and exit angles of the telescope in agreement with those worked out by Fairchild and Hoover for good disappearance of the filament. Non-disappearance of the filament, however, was observed in only one pyrometer. This has been shown to be due to the low resolving power of the eye-pieces employed. In consequence the reproducibility of reading is not as high as possible. For a high magnification it is an advantage to use a Huygens eye-piece and a flat-windowed lamp to reduce distortion. A flat filament makes possible larger entrance and exit angles than may be used with a cylindrical filament and hence a brighter field is possible. This enables much lower-temperature sources to be measured.

(3) *The Monochromatic and Absorption Screens.*

The red glass and absorption screen combination was satisfactory from the point of view of giving a good colour match, except in one pyrometer where failure in this respect was due to the use of too light a red glass for combination with the particular absorption screen employed. This

absorption screen was selective, as were all the screens in varying degrees, but this is not a disadvantage in itself, provided that good colour matching can be obtained in conjunction with a suitable red glass. In one of the instruments, however, the use of a selective absorption screen necessitated the inclusion of an unsuitable monochromatic screen, which gave a low transmission and an effective wave-length differing widely from that normally obtaining. The black-body temperatures of a non-black-body source of emissivity about 0.4 (e.g., tungsten, molten steel), as read by two optical pyrometers having effective wave-lengths differing by 0.029μ (the range of wave-length encountered in the pyrometers examined), differ by 6°C. at 1600°C.

The desirability of employing a combination of red glass and absorption screen to give an absorption constant, K , which does not vary with the temperature of the source, has been mentioned.

The method of interposing the absorption screen between the filament and the source is a point of design which should receive some attention. In two of the pyrometers it was observed that the absorption screen was interposed by rotating it about an axis at right-angles to the axis of the telescope, and unless the "in" position is well-defined there is danger of the screen being tilted in the beam of radiation, thus causing the effective transmission of the screen to be reduced. It would seem preferable to rotate the screen about an axis parallel to the axis of the telescope or to use a slide at right-angles to the axis.

(4) *The Measuring Equipment.*

The brightness of the filament in four of the five pyrometers was measured in terms of voltage. In one of these a simple voltmeter across the lamp terminals was employed and the instrument suffered therefore from a very cramped scale; 10°C. equalled 0.7 mm. scale length at 800°C. and 1.0 mm. at 1500°C. on the low range, and about 0.6 mm. on the high range. The other three pyrometers had bridge circuits, enabling the use of the whole scale of the voltmeter. In one of these instruments the length of scale for 10°C. on the low range was 1 mm. at 800°C. and 2.7 mm. at 1400°C. The indicating instruments are obviously subject to some parallax error, which may amount to 2 or 3°C. on the low range and twice this on the high range of the pyrometer. The question of balance of the indicator is also of importance, since it may be read in any position. A difference of about 10°C. in reading from the horizontal to the vertical position of the telescope was observed in one instance. The temperature coefficient of the indicator may account for a difference of reading of $2\text{--}3^{\circ} \text{C.}$ on the low range for a change of 10°C. in ambient temperature, and about double this amount on the high range of the instrument. Two designs of bridge unit have been employed and, in one of these, spring contacts are used in the low-resistance arms of the bridge. When it is realized that a change of 0.01 ohm in the resistance of either of these arms produces a change of about 10°C. at a scale reading of 1600°C. , it is seen that such a design may cause error by change of the contact resistance.

The potentiometric system of measurement has been shown to be superior to the use of either an ammeter or a voltmeter, both from the point of view of elimination of many of the errors to which deflection instruments are subject and that of obtaining a more open scale. In the instrument employing a potentiometer, the scale was about four times the length of that obtained in any of the deflection instruments.

The general conclusion deduced from this examination of five different models of portable disappearing-filament optical pyrometers is that in four of them the combined effect of the various defects is to cause uncer-

tainties of measurement, in works practice, of about $\pm 10^{\circ}$ C. on the low range and $\pm 20^{\circ}$ C. on the high range of the instrument. The fifth instrument was not subject to appreciable errors of design, and the uncertainty of measurement with this pyrometer could probably be placed at about $\pm 3^{\circ}$ C. on the low range.

The work described in this paper was carried out at the National Physical Laboratory as part of the research programme of the Foundry Steel Temperature Sub-Committee, and is published by permission of the Director of the Laboratory. The pyrometers examined were lent for the purpose by Messrs. Hadfields, Ltd., Messrs. Thomas Firth and John Brown, Ltd., and The United Steel Companies, Ltd.

For Correspondence on this Paper see the *Journal*, 1946, No. I.

LOCAL HEATING IN PLAIN CARBON STEELS.*

MARTENSITE FORMED FROM PEARLITE.

BY DR.-ING. W. J. WRAŻEJ (IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, LONDON).

(Figs. 1 to 10 = Plates XIX. to XXII.)

SYNOPSIS.

This paper describes the examination of certain samples of steel, parts of which had been subjected to various types of local heating, notably from the blast of hot gases and by friction. In each case a shallow martensitic layer was produced, and it is shown that the temperature reached the Ac_1 , but not the Ac_3 point.

The composition of eutectoid steel is considered and it is deduced that it contains 0.888% of carbon. The structure of martensite in eutectoid steel, its ease of production and possible reasons for its stability are also discussed.

(1) *Introduction.*

THE purpose of this paper is to discuss various effects arising from the localized heating of some carbon steels. The problem arose from an investigation of the hardened layer produced on a shell which had been subjected to a blast of hot gases when fired from a gun. The nature of this layer is considered below, together with some experiments in which the localized heating of eutectoid steels was produced by friction. As would be expected, the effect of localized transient heating depends only on the temperature reached and not on the mode of application of the heat.

(2) *Experimental.*

Owing to the fact that steel undergoes allotropic modifications when the temperature rises above the allotropic change points, some heating effects are accidentally produced on the surface of shells and steel driving bands which are exposed to escaping gases during the firing of guns. In such cases a hardened layer from 0.05 to 0.08 mm. deep has been observed. The appearance of this layer, however, indicates that the temperature has not reached the Ac_3 point, although it has exceeded the Ac_1 (723°C.) point.

Fig. 1 shows the depth of the hardened layer on a carbon steel shell after firing. This steel contained approximately 0.45% of carbon, 0.9% of manganese, 0.30% of silicon and 0.04% each of phosphorus and sulphur. Pearlite grains have been transformed into martensite, which is more resistant to etching than pearlite. As shown in Fig. 2 at a magnification of 1200 diameters, there is no transition zone between the martensite and pearlite. It is noticeable that ferrite grains persist up to the surface and are not dissolved in the austenite formed during heating. This shows that the Ac_3 point of this steel had not been exceeded.

Fig. 3 is another example which represents a section of a steel driving

band (carbon 0.27%, manganese 0.90%, silicon 0.06%, phosphorus and sulphur 0.02% each) attached to the shell described above. Martensite grains (white) are sharply distinguished from the ferritic background and pearlite grains (dark). Fig. 4 shows a single pearlite grain after shallow surface heating, *i.e.*, only a small part of the grain has been transformed into martensite. This particular grain is cut by a ferrite grain and is surrounded by others. It is evident that this intersecting ferrite grain remains unchanged—*i.e.*, sharply separated from martensite—up to the surface, confirming that during heating the Ac_3 point was not exceeded.

It can be seen from these micrographs that some of the pearlite grains have been only partially transformed into martensite grains and that the sharp boundary between the hardened layer and the parent material shows the depth to which the Ac_1 temperature penetrated.

The existence of the martensitic structure proves not only that the Ac_1 point was reached, but also that the cooling rate after heating was sufficiently rapid to cause a quenching effect from the Ac_1 temperature. The great bulk of the cold parent material underneath the heated zone, as well as the blast of cooling air shortly after emergence from the muzzle, provided the necessary quenching.

Finally, the ease with which the pearlite grains were transformed into martensite must be noted.

Further deductions have been based upon some simple experiments designed to produce local martensitic transformation.

It has been shown by Bowden and Hughes¹ that when one piece of metal slides over another the work done against friction appears as heat generated locally at many small points of contact between the two metal surfaces. Since these contact areas are very small, the temperature locally may temporarily reach quite a high value. The opinion has frequently been expressed that such high local temperatures actually reach the melting point. In the case of steel-to-steel friction, no evidence has been found to support such a view. On the other hand, owing to the heat developed locally, the metal can become sufficiently soft and plastic to yield to, or even be removed by, the pressure.

Let us consider some examples in which the heat developed by friction has been recorded in a natural way, *i.e.*, by structural changes in the material.

An ordinary hard steel (carbon 0.5%, manganese 0.8%) was cut with a hacksaw. After slight and careful polishing, micro-examination (Fig. 5) revealed distorted grains in the parent material. Fig. 6, an enlargement of part of Fig. 5, shows that some of the pearlite grains had been transformed into martensite. Similar effects were observed in this hard steel and in a soft (carbon 0.18%) steel when both were ground on a grinding wheel and then lightly polished (Figs. 7 and 8).

The above experiments show that friction can easily produce sufficient local heating to bring the surface temperature above the Ac_1 point, at which the pearlite changes into austenite, which, in turn, changes into martensite on rapid cooling. The cooling is naturally rapid, owing to the dissipation of the heat into the body of the metal and to the chilling effect of the cold air in contact with the surface. It may be noticed in this connection that Trent² has described a martensitic layer produced by the friction between adjacent wires in wire ropes.*

* Sir W. C. Roberts-Austen in a "Report of the Committee appointed by the Board of Trade to Enquire into the Loss of Strength in Steel Rails through Use on Railways," presented to both Houses of Parliament by Command of Her Majesty (London, 1900: H.M. Stationery Office), showed by micro-examination "the alteration of the surface of a rail by wear" and stated that "the lighter portion contains martensite, which shows that the rail had been locally hardened." That portion of material 0.01 in. in thickness represents a martensite with a net of ferrite (Fig. 3, Plate IV. of the Report).

If we consider the ease of the pearlite-martensite transformation and its resistance to further change, we are led to the conclusion that the martensite produced from pearlite is one of the most stable forms of this metastable phase. It is this quality which lends importance to steel of eutectoid composition.

(3) *Iron-Carbon Eutectoid Steel.*

The composition of the eutectoid has been variously fixed by different investigators. Bain³ and the "Metals Handbook" of the American Society for Metals give the composition as 0.8% of carbon. On the other hand, Carpenter and Robertson⁴ give the composition as 0.87% of carbon. There is evidence that neither of these values is quite correct.

Petch⁵ and Lipson and Parker⁶ proved that martensite has a tetragonal structure. Carpenter and Robertson⁴ stated that this structure is due to the modification of the cubic iron lattice by the inclusion of carbon atoms. Petch and Lipson and Parker showed that in the α -iron unit cell there are six available positions for the carbon atoms, of which, according to Petch, only one-twelfth are occupied. The tetragonality of a 1.57% carbon steel quenched from 1000° C. is given⁶ by $c/a = 1.066$, where $a = 2.847$ kX. and $c = 3.037$ kX. ($a = 2.8604$ kX. in ferrite). The mean value of the displacement of an iron atom in the α -iron lattice can, as stated by the above authors, alter with the carbon content.

When a hypereutectoid steel is quenched certain features are apparent. In order to bring into solution the whole of the free cementite, a higher temperature is needed than that required for eutectoid steel. The result of such heat-treatment is the retention of a certain amount of austenite with the martensite. This has been corroborated by the many authors quoted by Epstein,⁷ and is also evident in Fig. 9 (a), an X-ray picture of a rod of case-hardened mild steel (carbon 0.15%), heated to 900° C. for 10 hr. and then oil-quenched. The austenite lines A_3 , A_4 , A_8 , A_{11} , and A_{12} can be identified as well as the martensite lines M_2 , M_4 , M_6 , and M_8 . On the other hand, if the temperature is not raised sufficiently to bring all of the cementite into solution, this constituent should persist after quenching.

To simplify the identification of martensite and austenite lines in quenched steels, electrolytic iron and copper are shown in Figs. 9 (b) and 9 (c), respectively. The photographs were all taken using $\text{Co } K_\alpha$ radiation and an iron filter.

When austenite is present, even in traces, one can never be certain how much of the carbon remains in the austenite and how much has gone into the martensite. When, however, free cementite exists in a hypereutectoid steel quenched from exactly the A_{c1} temperature, the martensite formed can contain only the amount of carbon associated with pearlite.

In the case of steel of hypo-eutectoid composition, where the temperature has not reached A_{c3} an excess of ferrite will be present. Such is the case in the mild-steel driving band described above. If the A_{c3} temperature had been exceeded, it would have been difficult for the austenite to have changed into martensite without the precipitation of ferrite. Such conditions generally reveal themselves by the presence of bainite as well as martensite, *i.e.*, by showing A_{r1}' and A_{r1}'' transformations.

The above argument suggests that a "true" martensite should be expected in quenched plain carbon eutectoid steel. The pearlite grains transformed into martensite in the steels described above are an example of this.

A further experiment was made. A rod was cut from the transition zone (showing ferrite and martensite) of a specimen of case-hardened mild steel (carbon 0.15%) which had been heated to 900° C. for 10 hr. and then oil-quenched. X-ray pictures were taken of the rod to see whether

they indicated the presence of the two structural components. Fig. 10 (a) shows the result of this experiment. For comparison, Fig. 10 (b) illustrates the result obtained with a rod taken from the centre of the same mild-steel specimen. In (a) the lines are all broader than those in (b), and, further, in (a) the low-angle line 110 is a doublet. The second line of this doublet is due to ferrite and the first to the quenched component (austenite).^{*} More detailed consideration of this point will be published in due course.

As shown in Fig. 3, the surface layer of the mild-steel band consists of martensite embedded in ferrite. A very thin flake was cut from the surface of the band and carefully ground, in the hope that all of the parent

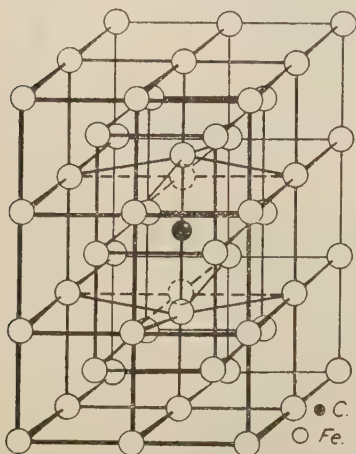


FIG. 11.—Atomic Arrangement in Martensite in Eutectoid Steel. One carbon atom distorts twelve α -iron unit cells. For clarity only two displaced iron atoms shown.

See *Journal of The Iron and Steel Institute*, 1944, No. I., p. 137 P, Figs. A and B.)

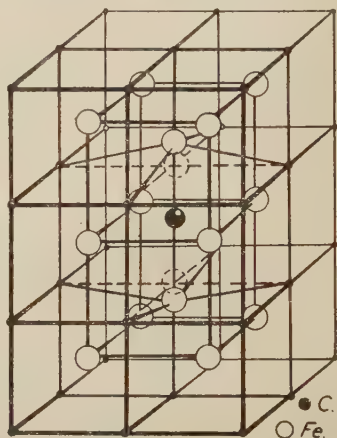


FIG. 12.—Simplified Drawing of Fig. 11 (iron atoms at corners indicated by dots), showing displacement of iron atoms and that the carbon atom on one edge of the first set of simple cubes must be regarded as situated in the face of the second set of simple cubes.

material would be removed. Fig. 10 (c) is an X-ray picture of this flake, whilst Fig. 10 (d) is a picture of the parent material inside the band. The similarity of Figs. 10 (c) and (d) to Figs. 10 (a) and (b) is most marked, although the doublet in (a) is not distinctly resolved in (c). There is thus a certain amount of quantitative evidence that the presence of martensite grains can be detected by X-ray examination.

A calculation⁸ of the number of carbon and iron atoms involved shows that in the martensite formed in a eutectoid steel, one single carbon atom is situated among 12 unit cells of iron, which suggests a eutectoid composition of 0.888% C.[†] That appears to be the most probable pearlite composition in plain carbon steel. One carbon atom inserted among the 12 unit cells of iron must distort them, because there are no interstices large enough to accommodate a carbon atom of radius 0.77 Å. without the displacement of neighbouring atoms.

^{*} Ferrite, 110 line; austenite, 111 line.

[†] Carbon, % = $\frac{100 \times 12.01}{24 \times 55.84 + 12.01} = 0.88820\%$.

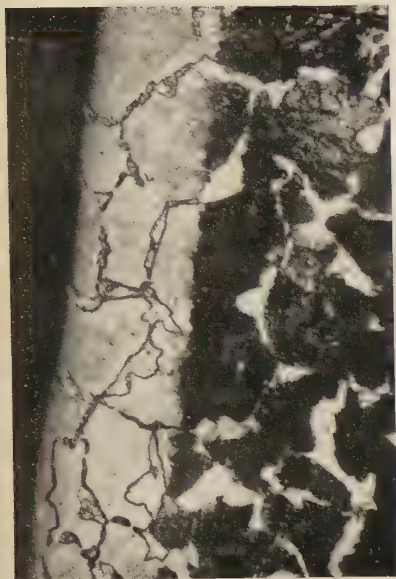


FIG. 1.—Depth of Hardened Layer on 0.45% Carbon Steel Shell after Firing. $\times 200$.

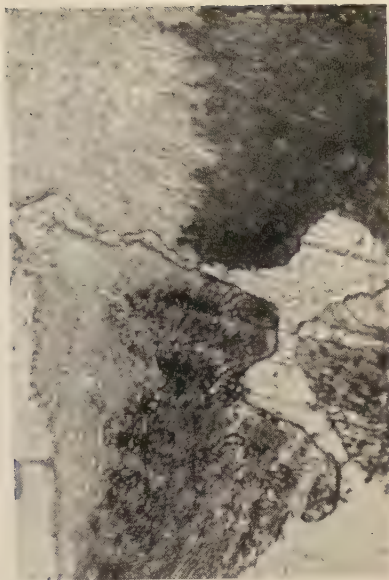


FIG. 2.—Martensite/Pearlite Boundary in Fig. 1 at higher magnification. $\times 1200$.

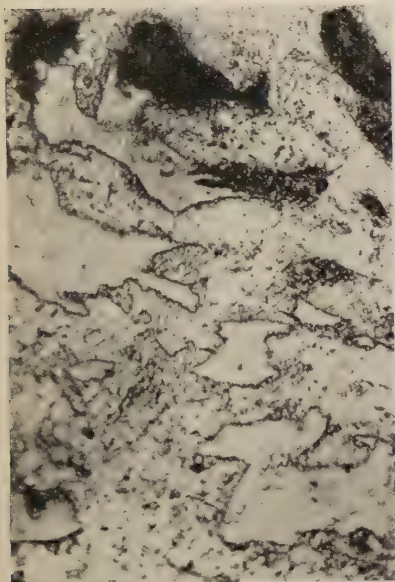


FIG. 3.—0.27% Carbon Steel Driving Band; martensite (white) sharply distinguished from ferritic background and pearlite grains (black). $\times 500$.

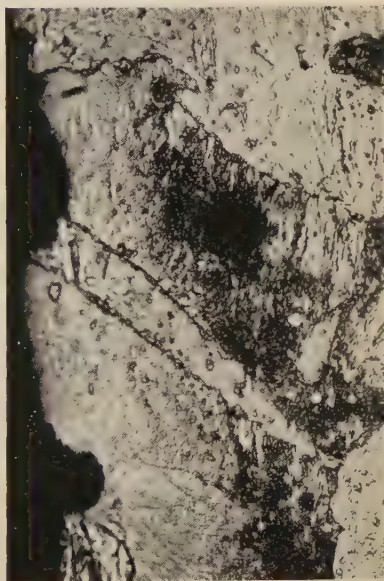


FIG. 4.—Single Pearlite Grain after Shallow Surface Heating (small part transformed to martensite). Grain cut by ferrite. $\times 1200$.

FIGS. 1 to 4.—Etched with Nital

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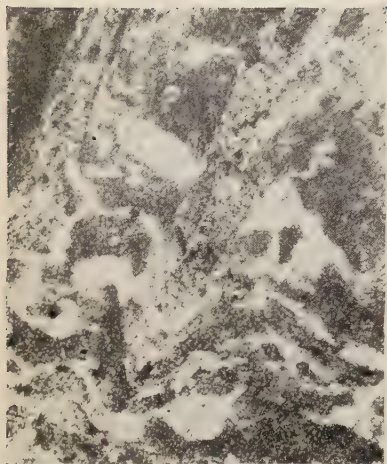


FIG. 5.— $\times 180$.

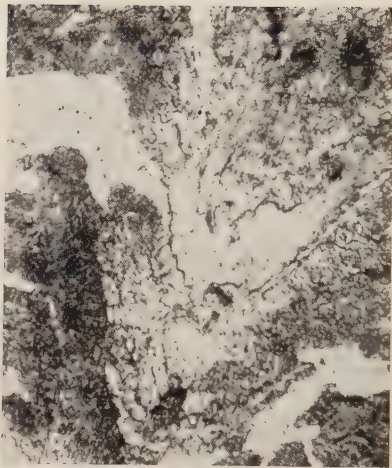


FIG. 6.— $\times 600$.

FIGS. 5 and 6.—0.5% Carbon Steel cut with a Hacksaw.

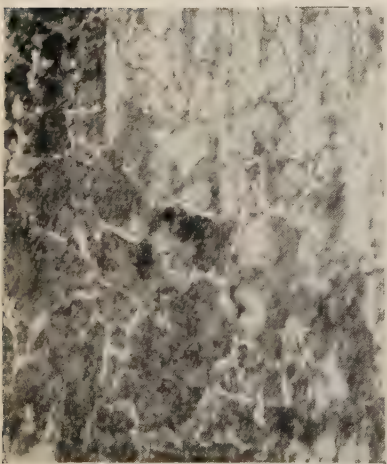


FIG. 7.—0.5% Carbon Steel, after grinding $\times 150$.



FIG. 8.—0.18% Carbon Steel, after grinding, $\times 600$.

FIGS. 5 to 8.—Pearlite Grains Transformed into Martensite. Etched with Nital.

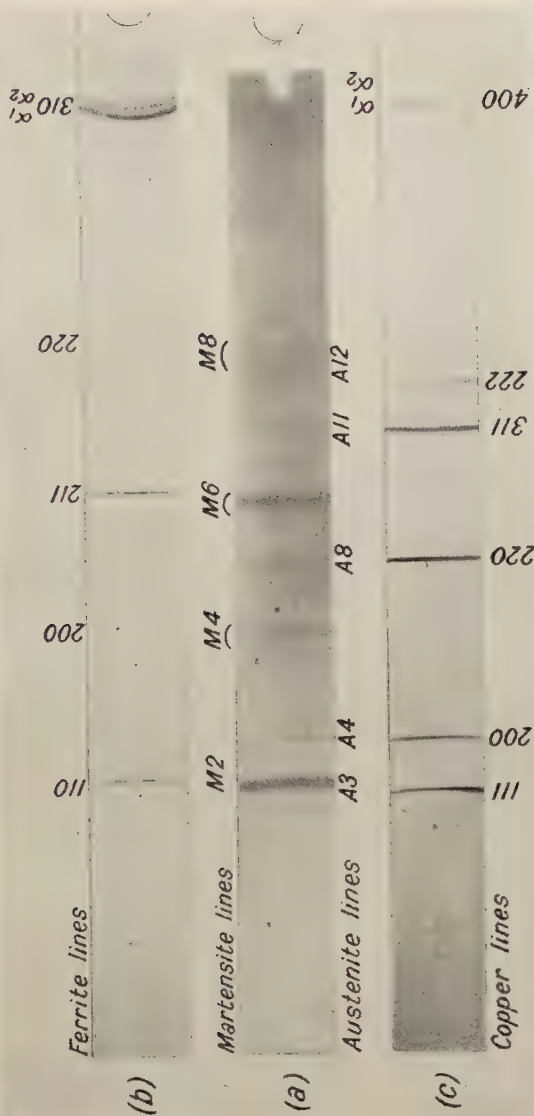


FIG. 9.—X-Ray Films; 9-cm. camera, $\text{Co K}\alpha$ radiation, iron filter. (a) Case-hardened steel oil-quenched from 900°C . (b) Electrolytic iron. (c) Electrolytic copper.

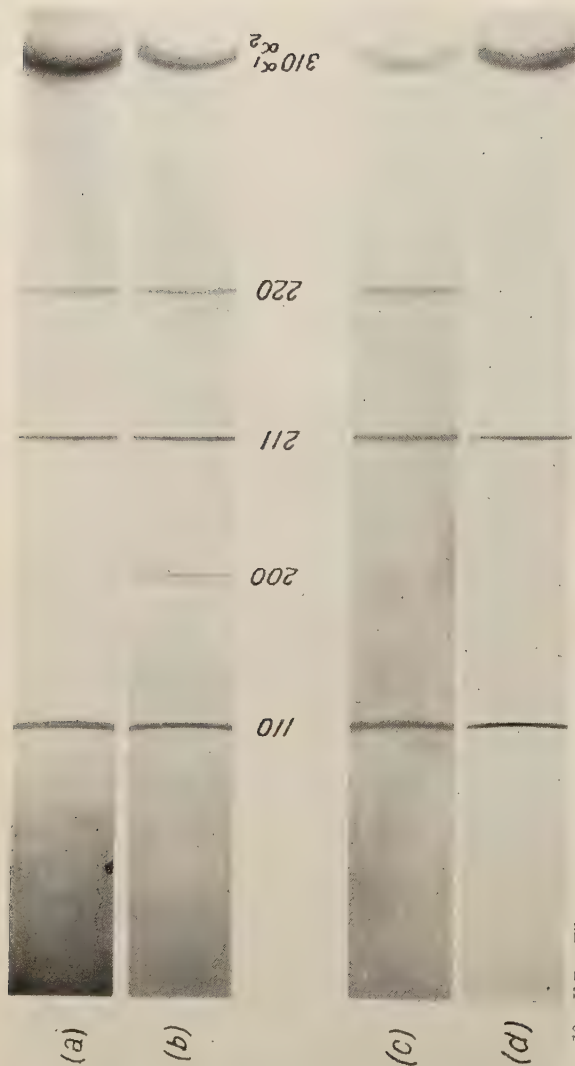


FIG. 10.—X-Ray Films; 9-cm. camera, Co $K\alpha$ radiation, iron filter. (a) Transition zone, (b) centre, of a case-hardened steel oil-quenched from 900° C. (c) Surface layer, (d) parent metal, of the mild-steel band (see Fig. 3).

a limiting diaphragm on the entrance cone of radiation, which thus varies with the focal distance of the objective.

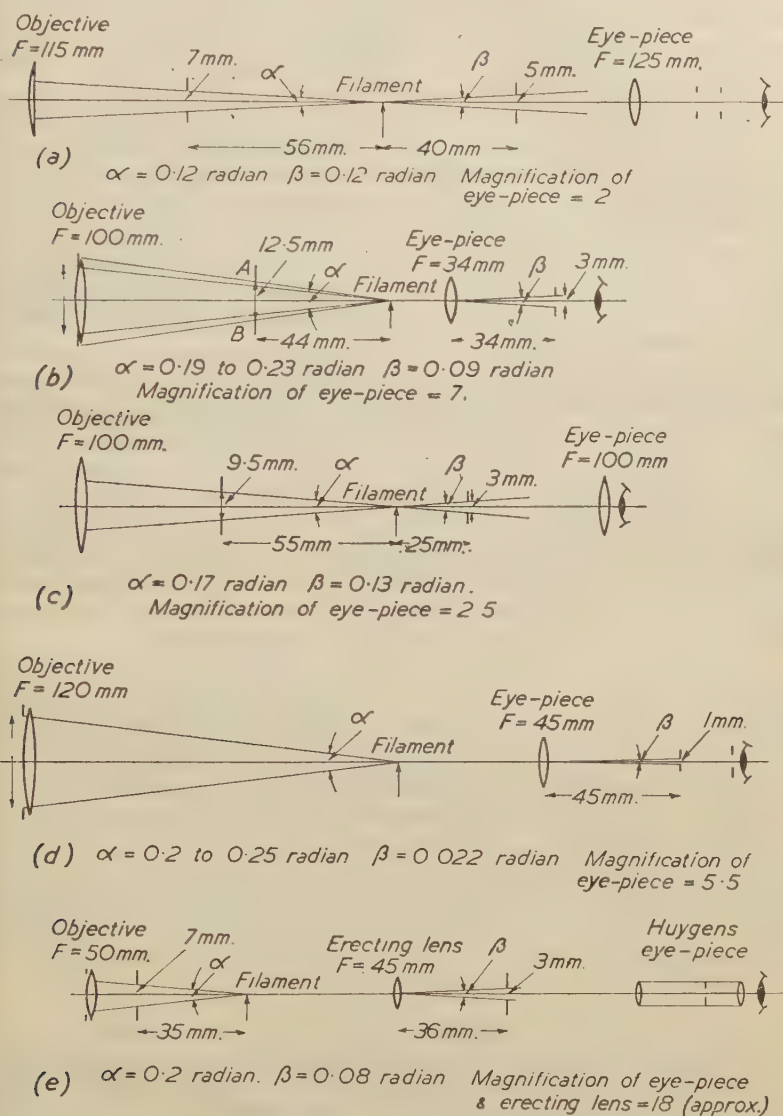


FIG. 4.—Optical Systems of the Five Pyrometers Examined.

The third example, Fig. 4(c), suffers from the same defect of incorrect diaphragming; both angles are too large. The magnification is too low to take advantage of the resolving power and so disappearance is obtained

at the expense of precision in matching. The optical system here suffers also from a further defect in that there is no pupil diaphragm fitted.

In Fig. 4(d), the resolving power of the ocular is only 0.03 mm. and, although the magnification is sufficient, this is not high enough to detect the edging of the filament. Thus disappearance is obtained by excessive reduction of the resolving power. No limiting diaphragm on the entrance cone of radiation is provided.

In Fig. 4(e), the angles α and β are seen to conform with those specified in Table IV. for flat filaments. The resolving power in this arrangement, 0.008 mm., is seen to be twice the maximum attainable, 0.015 mm., for the cylindrical filaments. The magnification of the eye-piece is quite adequate to take full account of this resolving power and so high precision of matching is obtained. Under the correct conditions for perfect disappearance of the filament with adequate resolving power and magnification, a brighter field is obtained by reason of the larger angles permissible. It is observed that high magnification of the eye-piece is here obtained by the use of a Huygens eye-piece, with the consequent advantage of a much improved image.

Attention has been drawn in the above comments to the absence of a limiting diaphragm between the objective and the filament in two examples. Although, for perfect disappearance under the best conditions, it is necessary to have a diaphragm in this position fixed relative to the filament, it is not generally the limiting diaphragm of the system, this being determined by the eye-piece diaphragm. The cone of radiation entering the eye is therefore constant for different positions of the objective. In the case of cylindrical filaments, however, the brightness of the filament is slightly affected by reflection of incident light at the edges of the filament, and variation of the entrance cone will thus produce a very slight variation in the apparent brightness of the filament. It would, therefore, apart from the reasons of good disappearance, be more satisfactory to have a diaphragm to keep the entrance angle of the telescope fixed.

It will be noted that in Fig. 4(d) and (e), the exit diaphragm is placed between the eye-piece lens and the eye, approximately at the focus of the lens. This arrangement is to be preferred to others, in which this diaphragm is between the filament and the lens, since a wider field of view is obtained with greater uniformity of illumination. The larger field of view adds considerably to the ease of sighting on the object.

In the five examples given of the optical systems in use we thus see that in one only, the fifth, are ideal conditions for good disappearance of the filament attained. The large angles are presumably adopted in order to have sufficient field brightness at the lower end of the scale. The problem may be dealt with, as in Fig. 4(e) by the use of a flat filament, or, where cylindrical filaments are employed, by the complete removal of the red glass screen for temperatures of the source below 800° C. The effect of this on the accuracy of the temperature measurements is discussed in the next section.

III.—THE MONOCHROMATIC AND ABSORPTION SCREENS.

A disappearing-filament optical pyrometer may be operated quite satisfactorily at low intensities, 650–1000° C., without using a colour screen. Provided the calibration has been carried out for black-body radiation and temperature measurement is made on a black body, no error will result. If measurement is made on a non-black body, the wave-length to which the temperature is to be ascribed must be specified, in this case the Crova wave-length. It is found that at temperatures higher than 1000° C. a difference of colour between the tungsten filament

of the lamp and the black-body source becomes apparent, and so complete disappearance of the filament cannot be achieved. Thus it is necessary, in order to eliminate this colour difference and also to define the effective wave-length more precisely, to limit the wave-band of light used. This would be most satisfactorily achieved, were it not for the small quantity of light consequently available, by the use of strictly monochromatic light, such as given by a spectroscope, for no matter what the spectral distribution of the source as compared with that of the filament, satisfactory matching of both brightness and colour could always be obtained. It has been shown, however, that satisfactory results can be achieved by the use of a carefully chosen so-called monochromatic glass screen, with the additional advantage of far greater luminosity; this is one of the more important reasons for selecting a red glass screen for this purpose. The red glass employed in an optical pyrometer usually has a wave-length cut-off on the short wave-length side at about 0.61μ and a steep rise in transmission to 80-90% in the region $0.65-0.75 \mu$ and beyond. The limit of visibility of the eye is at about 0.70μ , rising to some 55% at 0.60μ and thus the effective band of light lies between 0.60 and 0.70μ , with a sharp maximum in the region $0.64-0.65 \mu$.

For temperature measurements on a black body without an absorption screen, it is not necessary to know any more about the red screen than that sufficient sensitivity and reproducibility of reading are obtainable. If, however, a non-black-body source is used, it is important to know the wave-length employed in the pyrometer, for the brightness of such a source, relative to that of a black body at the same temperature, varies with the wave-length. In other words the apparent, or black-body, temperature of the source is a function of the wave-length. It may be shown that, if T_1 is the black-body temperature of the source for a wave-length λ_1 , and T_2 that for a wave-length λ_2 then :

$$\frac{1}{T_2} = \frac{\lambda_2 - \lambda_1}{\lambda_1} \left(\frac{1}{T_1} - \frac{1}{T_c} \right) + \frac{1}{T_1} \quad \dots \dots \dots (1)$$

where T_c is the colour temperature of the source. Since, as indicated above, the wave-band operative has finite width, it is necessary to determine the effective wave-length, which is defined as follows. If E_1 is the energy radiated by a black body at a temperature T_1 , and E_2 that at a temperature T_2 , then the wave-length must be so chosen as to give :

$$R = \frac{E_1}{E_2} = \frac{L_1}{L_2},$$

where L_1 and L_2 are the corresponding luminosities through the screen in question. From Wien's law :

$$\log R = \frac{C_2}{\lambda} \left(\frac{1}{T_1} - \frac{1}{T_2} \right) = \log \frac{L_1}{L_2}$$

$$\therefore \lambda_c = \frac{C_2 \left(\frac{1}{T_1} - \frac{1}{T_2} \right)}{\log \frac{L_1}{L_2}}$$

for the interval T_1 to T_2 .
Since :

$$L = \int_0^{\infty} E_{\lambda T} V_{\lambda} d\lambda,$$

where V = the visibility function of the eye and t = the transmission of the monochromatic screen, in the limit when T_2 approaches T_1 :

$$\lambda_T = \frac{\int_0^\infty E_{\lambda T} V_{\lambda} t_{\lambda} d\lambda^*}{\int_0^\infty E_{\lambda T} \frac{1}{\lambda} V_{\lambda} t_{\lambda} d\lambda},$$

which is known as the limiting effective wave-length.

It is also necessary to know the effective wave-length of the red glass, if it is required to extrapolate the scale by means of an absorption device

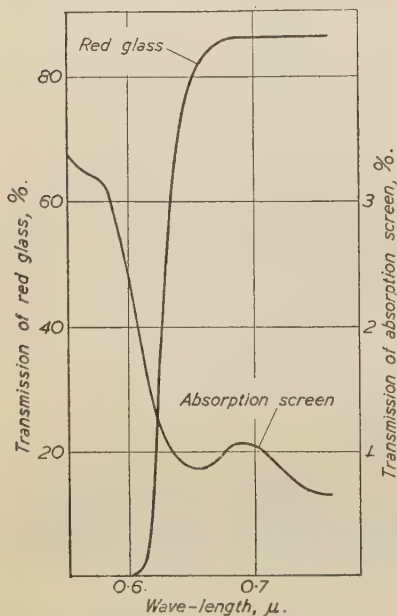


FIG. 5.—Pyrometer A. Glass thickness, 4.01 mm.; screen thickness, 2.44 mm.; $\lambda = 0.647$.

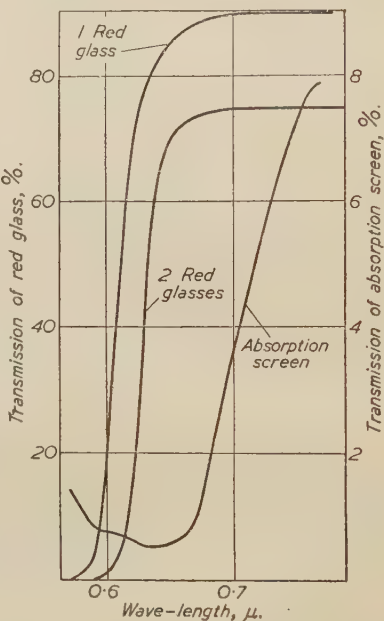


FIG. 6.—Pyrometer B. With one glass $\lambda = 0.634$; with two glasses $\lambda = 0.647$. Screen thickness, 1.23 mm.

such as a rotating sector or absorption glass. From Wien's law the temperature interval for a transmission factor, R , of the absorption device is given by :

$$\frac{1}{T_1} - \frac{1}{T_2} = \frac{\lambda \log R}{C_2} \quad \dots \dots \dots (2)$$

When an absorption device is interposed between the filament and the source, the red glass must be chosen with greater care than formerly in order to ensure good colour matching. This is on account of the difference of the energy-wave-length distribution at the two temperatures, and thus although the intensity of the source may be reduced by the absorption device to that of the filament it does not produce the same colour. The colour difference will obviously be greater the smaller the

* Foote : U.S. Bureau of Standards Bulletin, 1916, vol. 12, p. 484.

transmission factor. Conditions become even more stringent when the absorption screen is appreciably selective. Where the screen transmits more on the short than on the long wave-length side of the band, it may be necessary to use a deeper red glass; if the reverse is the case it may not be possible to eliminate the colour difference without introducing an additional screen to cut off on the long wave-length side of the band.

It will be realized that if a pyrometer is calibrated over its whole range by comparison with a standard pyrometer or source, such as a tungsten-strip lamp, the neutrality, as such, of the absorption screen is not important, provided that the colour matching of the filament against the background is satisfactory. The effective wave-lengths of the two

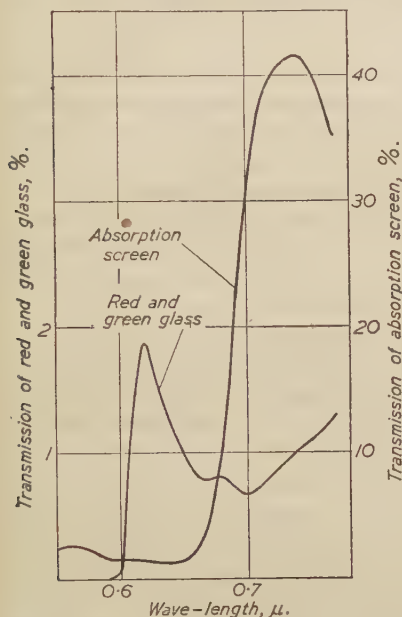


FIG. 7.—Pyrometer C. Combined glass thickness, 4.04 mm.; screen thickness, 2.98 mm.; $\lambda = 0.626$.

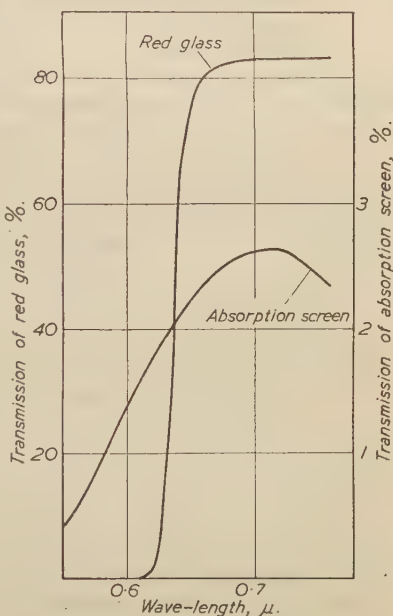


FIG. 8.—Pyrometer D. Glass thickness, 2.06 mm.; screen thickness, 1.29 mm.; $\lambda = 0.648$.

FIGS. 5 to 8.—Transmissions of Red Glass and Absorption Screen for Pyrometers A to D.

pyrometers being compared should be the same or, if they differ, a correction should be applied as indicated above.

To recapitulate, the requirements of the red glass and the absorption screen are as follows :

- (1) *With no absorption screen and a black-body source :*
The red glass needs only to give a good colour match.
- (2) *With no absorption screen and a non-black-body source :*

The wave-length of the red glass must be known, since the brightness relative to a black body is a function of the wave-length.

(3) *When an absorption screen is used:*

(a) The combination of red glass and absorption screen must give a good colour match.

(b) *Non-black-body source.*—The wave-length of the red glass must be known, for the same reasons as given in (2) above.

(c) *Extrapolation by means of the absorption constant.*—The absorption constant depends on the wave-length of the red glass and this should therefore be known. Strict neutrality of the absorption screen is desirable over the relevant wave-band.

(d) *Calibration by comparison with a standard pyrometer or source.*—The neutrality of the absorption screen is not important, provided that conditions 3(a) and 3(b) are taken into consideration.

In order to determine how nearly the above-stated requirements were satisfied in the pyrometers examined, the transmissions of the red glasses and absorption screens were measured; * the curves are given in Figs. 5 to 9. On each curve is given the effective wave-length of the red glass for a brightness temperature of the source of 1600°C . The range of wave-lengths is $0.626\text{--}0.655\mu$ and this represents a difference of 6°C . in the black-body temperature of a tungsten source at 1600°C . In the case of pyrometer *A* (Fig. 5) there was a lack of colour match, and this may be attributed to the use with the absorption screen employed of a red glass transmitting too far into the short wave-length end of the band. Thus, if a red glass having a transmission comparable with that of pyrometer *E* is employed, the colour difference is eliminated. Pyrometer *C* had a combination of red and green glass screens, giving a transmission as shown in Fig. 7. The two components were placed sufficiently close together to produce interference fringes, and the transmission would thus vary with the part of the screen employed. The transmission of this combination is seen to be much lower than with the other screens, resulting in an unnecessary loss of light, whilst the effective wave-length is very much lower than is usually obtained; consequently care is needed in applying the necessary correction when comparisons are made with other pyrometers sighting on a non-black-body source. Obviously the absorption screen used here is unsuitable, on account of the very sharp rise in transmission towards the long wave-length end of the band. Thus, at 0.65μ the transmission is 2.4% and at 0.7μ , 32%. The use of any of the red glasses here discussed with this absorption screen would not eliminate colour difference; hence the addition of the green glass above-mentioned. In the case of pyrometer *B* there is also a rise in transmission of the absorption screen between 0.67 and 0.70μ , but this rise is not of the same order as in the previous example, being only from 1 to 3.6%, and this is apparently insufficient to produce any appreciable colour difference with the type of red glasses usually employed. In connection with the curves given for the red glasses in this instance, only very approximate measurements were possible on account of the extremely small area of glass available. The absorption screen of pyrometer *D* has also an appreciable slope in the same direction as in the two previous cases, from $5\frac{1}{2}\%$ at 0.62μ to $10\frac{1}{2}\%$ at 0.7μ , but no colour difference is here produced; however, the transmission of this glass is much greater than those of the other glasses, being about 6% (compared with between 1 and 2%), thus making conditions more favourable to good colour matching. The red glass and absorption screen combination employed in pyrometer *E* pro-

* These measurements were made by the Light Division of the National Physical Laboratory.

duced good colour matching, but it should be noted that the maximum scale reading in this pyrometer was 1750° C.

It has been mentioned that it is advantageous to have a combination of red glass and absorption screen which gives a constant value to the absorption factor :

$$K = \frac{1}{T_1} - \frac{1}{T_2} = \frac{\lambda \log R}{c_2},$$

no matter what the value of the temperature of the source. If this is achieved, extrapolation by means of such a combination may be carried out with greater accuracy. The calibration of the pyrometer also becomes a very much simpler matter, as a single determination of this constant suffices to fix the complete high range of the pyrometer by reference to the first range. In illustration of this point the values of transmission factors and absorption constants for pyrometers *A* and *E* over the high-temperature range of the instruments are given in Figs. 10 and 11. The variation of the absorption constant with temperature of the source for pyrometer *E* is negligible. Evidently in this case some importance has been attached to the necessity for producing an invariable absorption constant. In each of these cases the factors have been calculated from the transmission curves of the absorption screens in conjunction with the appropriate red glass transmissions and the effective wave-lengths applying to the temperature intervals produced by the absorption screens.

The effect of the change of air temperature on the pyrometer reading due to changes in the transmission of the absorption screen was measured by separating the absorption screen from the pyrometer, placing it between the objective and the source, and heating it to 50° C. A rise of about 30° C. in the ambient temperature in no case produced a greater change than about 3° C. in the reading, at a source brightness of 1600° C.; this gives a coefficient of 0.1, which is quite negligible for most practical purposes. The transmission of the glass becomes less as the temperature rises, and in general the change is greater the steeper the slope of the transmission-wave-length curve. This, then, is an additional reason for using, for high precision, an absorption screen as strictly neutral as is possible.

The temperature coefficients of the red glasses were not measured, since they are not likely to be sufficiently great to be of importance in the accuracy of measurement with which we are here concerned. Measurements have been made on various red glasses and these show that the transmission curve moves towards the long wave-length end of the spec-

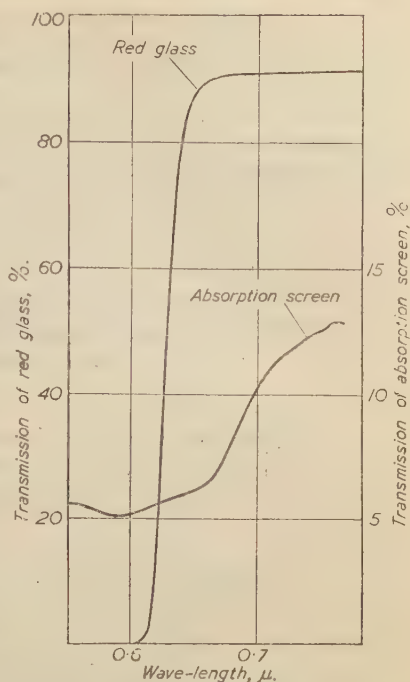


FIG. 9.—Transmissions of Red Glass and Absorption Screen of Pyrometer *E*. Glass thickness, 2.82 mm.; screen thickness, 3.34 mm.; $\lambda = 0.655$.

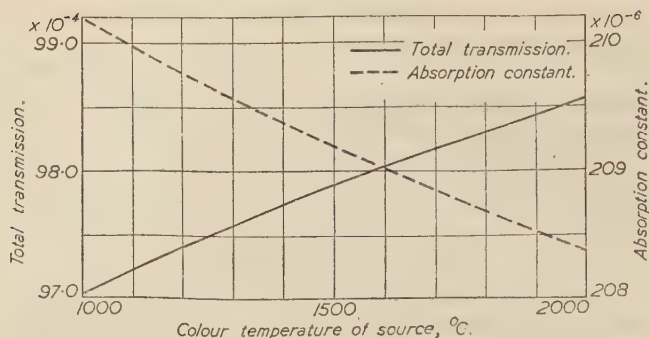


FIG. 10.—Pyrometer A.

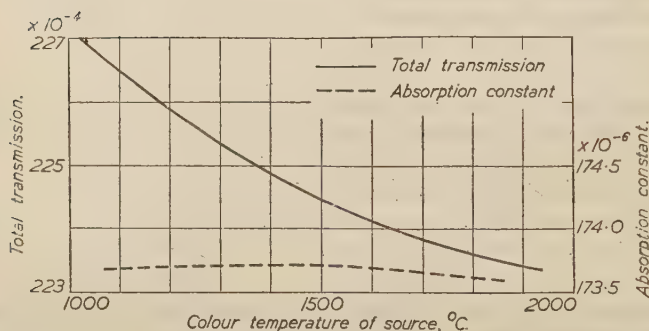


FIG. 11.—Pyrometer E.

FIGS. 10 and 11.—Transmission Factors and Absorption Constants over High-Temperature Range.

trum as the temperature is increased. The change amounts to about 0.001μ in effective wave-length for 10°C . change of temperature; at a source temperature of 1600°C . this is equivalent to about 1°C . when an absorption screen giving a reduction of 0.01 is employed.

IV.—THE MEASURING EQUIPMENT.

It has been mentioned previously that the pyrometer may be calibrated in terms of current or of voltage, and the advantage of the latter method has been explained. Where the lamp filament is sufficiently long to be free of end-effect, current measurement, for well-known reasons, is to be preferred. For precision work the current is determined by measuring the potential drop on a standard resistance in series with the lamp, by means of a potentiometer. With the commercial pyrometer, in the interests of compactness and portability, it is customary to use an ammeter or voltmeter. In either case a simple circuit has certain disadvantages, the chief of which is that the full scale of the instrument cannot be usefully employed without some device for setting back the zero; otherwise the point at which the filament becomes visible is when the ammeter or voltmeter needle is some half-way up the scale. Thus the scale becomes very cramped and there is a loss of accuracy of reading. The most satisfactory

method adopted for overcoming this difficulty is to make the lamp one arm of a Wheatstone bridge. The bridge is balanced for the lowest temperature to be measured, and thus the full scale of the galvanometer may be employed.

Three of the pyrometers under review had such bridge systems. Two of these had the circuit design, due to Schofield and Gall* shown in Fig. 12(a). A new lamp may be inserted in this system without recalibrating the scale of the millivoltmeter, an important consideration in an industrial pyrometer. This is achieved by breaking the bridge circuit at the points marked *a*, *b*, *c*, and *d*, and inserting the new lamp complete with the resistances *P*, *R*, and *S*, adjusted to suit the calibration of the new lamp. It will be observed that a change of contact resistance at the points *a* and *c* is without effect upon the calibration. At *b* and *d* the change will, in general, be small compared with the total resistance of the arm. The third pyrometer used the bridge system shown in Fig. 12(b),

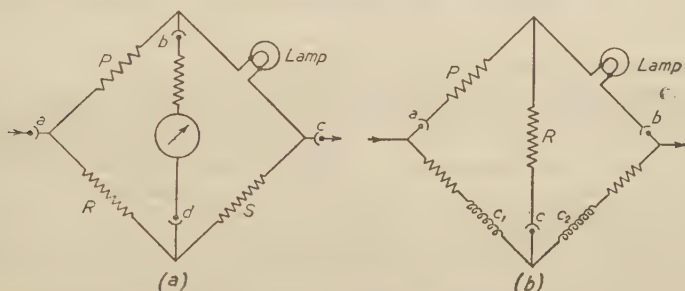


FIG. 12.—Circuit Design (a) in two of the bridge-system pyrometers and (b) in third bridge-system pyrometer.

where C_1 and C_2 are the coils of the differential galvanometer employed. Here the change of lamp is made by breaking the circuit at the points marked *a*, *b*, and *c* and replacing the resistances *P* and *R*. The contact resistances *a* and *b* are in the low-resistance arms (about 2 ohms) of the bridge and a change in their values would cause significant errors.

Another of the pyrometers had a simple voltmeter across the lamp and suffered, therefore, from the disadvantage of the cramped scale.

All four pyrometers so far discussed in this section were in one unit, the indicator being mounted on the telescope, and the question of the balance of the indicator movement thus becomes one of major importance. One only of these indicators showed a serious change of reading with position, a difference of 10° C. on the first scale being observed between the vertical and horizontal positions of the telescope. In one case, too, a marked "stickiness" of the movement was noted; the reading sometimes changed by about 5° C. on the first scale on tapping the indicator after making a setting.

From Table II. it will be observed that the temperature coefficient of the indicator, allowance being made for that of the lamp, may be as high as 0.25. Thus a substantial difference of reading may result from a change of ambient temperature of 10° C., being about $2\text{--}3^\circ$ C. in the low range and about twice this amount on the high range of the pyrometer.

The remaining instrument had a separate portable potentiometer and in effect employed a current-temperature calibration, in contrast to all the other instruments (which used a voltage-temperature relation). It

* *Journal of Scientific Instruments*, 1924, vol. 1, p. 193.

has been shown (Table II.) that the pyrometer lamp in this case has a negligible end-effect. The potentiometer system has important advantages over the other methods. The potentiometer galvanometer is a null instrument and therefore the changes due to position temperature coefficient, alteration of magnetic field or control are not of importance. Thus a relatively high-sensitivity galvanometer may be employed and a very open scale calibration obtained by the use of a long slide-wire. In this way the uncertainty of reading the scale is eliminated. Of course the instrument is not so compact as the others and two operations are required, one in making the brightness match, and the other in balancing the potentiometer, but the design is such that both may be rapidly carried out.

V.—CONCLUSIONS.

This section summarizes the conclusions to be drawn from the foregoing and also discusses a few additional points of design not already mentioned.

(1) *The Lamp Filament.*

The lamp filaments in four out of the five instruments examined are too short in relation to their diameters to give high-precision readings. Such short filaments are subject to temperature-coefficient and thermal-inertia errors. The temperature coefficient is shown to be less for a voltage-temperature than for a current-temperature calibration. The former system of measurement is employed in these four instruments and the coefficient for a filament of equivalent size to those in use is shown to be of the order of 1° C. on the low range of the pyrometer, for a change of air temperature of 10° C. The error on the high range would be of the order of twice this amount. The thermal-inertia effect becomes most serious when the reading is taken immediately after switching on the current. Thus with one of the pyrometers, a reading taken some 20 sec. after switching on, at a scale reading of 1000° C., was about 8° C. lower than the reading when thermal equilibrium had been reached. In order to be free of these effects the minimum length of a filament should be 60 mm. for a dia. of 0.06 mm., and 50 mm. for a dia. of 0.04 mm. The flat filament has been shown to be superior to the cylindrical filament in both respects.

(2) *The Optical System.*

In only one of the pyrometers were the entrance and exit angles of the telescope in agreement with those worked out by Fairchild and Hoover for good disappearance of the filament. Non-disappearance of the filament, however, was observed in only one pyrometer. This has been shown to be due to the low resolving power of the eye-pieces employed. In consequence the reproducibility of reading is not as high as possible. For a high magnification it is an advantage to use a Huygens eye-piece and a flat-windowed lamp to reduce distortion. A flat filament makes possible larger entrance and exit angles than may be used with a cylindrical filament and hence a brighter field is possible. This enables much lower-temperature sources to be measured.

(3) *The Monochromatic and Absorption Screens.*

The red glass and absorption screen combination was satisfactory from the point of view of giving a good colour match, except in one pyrometer where failure in this respect was due to the use of too light a red glass for combination with the particular absorption screen employed. This

absorption screen was selective, as were all the screens in varying degrees, but this is not a disadvantage in itself, provided that good colour matching can be obtained in conjunction with a suitable red glass. In one of the instruments, however, the use of a selective absorption screen necessitated the inclusion of an unsuitable monochromatic screen, which gave a low transmission and an effective wave-length differing widely from that normally obtaining. The black-body temperatures of a non-black-body source of emissivity about 0.4 (*e.g.*, tungsten, molten steel), as read by two optical pyrometers having effective wave-lengths differing by $0.029\ \mu$ (the range of wave-length encountered in the pyrometers examined), differ by $6^\circ\text{C. at } 1600^\circ\text{C.}$

The desirability of employing a combination of red glass and absorption screen to give an absorption constant, K , which does not vary with the temperature of the source, has been mentioned.

The method of interposing the absorption screen between the filament and the source is a point of design which should receive some attention. In two of the pyrometers it was observed that the absorption screen was interposed by rotating it about an axis at right-angles to the axis of the telescope, and unless the "in" position is well-defined there is danger of the screen being tilted in the beam of radiation, thus causing the effective transmission of the screen to be reduced. It would seem preferable to rotate the screen about an axis parallel to the axis of the telescope or to use a slide at right-angles to the axis.

(4) *The Measuring Equipment.*

The brightness of the filament in four of the five pyrometers was measured in terms of voltage. In one of these a simple voltmeter across the lamp terminals was employed and the instrument suffered therefore from a very cramped scale; 10°C. equalled 0.7 mm. scale length at 800°C. and 1.0 mm. at 1500°C. on the low range, and about 0.6 mm. on the high range. The other three pyrometers had bridge circuits, enabling the use of the whole scale of the voltmeter. In one of these instruments the length of scale for 10°C. on the low range was 1 mm. at 800°C. and 2.7 mm. at 1400°C. The indicating instruments are obviously subject to some parallax error, which may amount to 2 or 3°C. on the low range and twice this on the high range of the pyrometer. The question of balance of the indicator is also of importance, since it may be read in any position. A difference of about 10°C. in reading from the horizontal to the vertical position of the telescope was observed in one instance. The temperature coefficient of the indicator may account for a difference of reading of $2\text{--}3^\circ\text{C.}$ on the low range for a change of 10°C. in ambient temperature, and about double this amount on the high range of the instrument. Two designs of bridge unit have been employed and, in one of these, spring contacts are used in the low-resistance arms of the bridge. When it is realized that a change of 0.01 ohm in the resistance of either of these arms produces a change of about 10°C. at a scale reading of 1600°C. , it is seen that such a design may cause error by change of the contact resistance.

The potentiometric system of measurement has been shown to be superior to the use of either an ammeter or a voltmeter, both from the point of view of elimination of many of the errors to which deflection instruments are subject and that of obtaining a more open scale. In the instrument employing a potentiometer, the scale was about four times the length of that obtained in any of the deflection instruments.

The general conclusion deduced from this examination of five different models of portable disappearing-filament optical pyrometers is that in four of them the combined effect of the various defects is to cause uncer-

tainties of measurement, in works practice, of about $\pm 10^{\circ}$ C. on the low range and $\pm 20^{\circ}$ C. on the high range of the instrument. The fifth instrument was not subject to appreciable errors of design, and the uncertainty of measurement with this pyrometer could probably be placed at about $\pm 3^{\circ}$ C. on the low range.

The work described in this paper was carried out at the National Physical Laboratory as part of the research programme of the Foundry Steel Temperature Sub-Committee, and is published by permission of the Director of the Laboratory. The pyrometers examined were lent for the purpose by Messrs. Hadfields, Ltd., Messrs. Thomas Firth and John Brown, Ltd., and The United Steel Companies, Ltd.

For Correspondence on this Paper see the *Journal*, 1946, No. I.

LOCAL HEATING IN PLAIN CARBON STEELS.*

MARTENSITE FORMED FROM PEARLITE.

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(Figs. 1 to 10 = Plates XIX. to XXII.)

SYNOPSIS.

This paper describes the examination of certain samples of steel, parts of which had been subjected to various types of local heating, notably from the blast of hot gases and by friction. In each case a shallow martensitic layer was produced, and it is shown that the temperature reached the Ac_1 , but not the Ac_3 point.

The composition of eutectoid steel is considered and it is deduced that it contains 0.888% of carbon. The structure of martensite in eutectoid steel, its ease of production and possible reasons for its stability are also discussed.

(1) *Introduction.*

THE purpose of this paper is to discuss various effects arising from the localized heating of some carbon steels. The problem arose from an investigation of the hardened layer produced on a shell which had been subjected to a blast of hot gases when fired from a gun. The nature of this layer is considered below, together with some experiments in which the localized heating of eutectoid steels was produced by friction. As would be expected, the effect of localized transient heating depends only on the temperature reached and not on the mode of application of the heat.

(2) *Experimental.*

Owing to the fact that steel undergoes allotropic modifications when the temperature rises above the allotropic change points, some heating effects are accidentally produced on the surface of shells and steel driving bands which are exposed to escaping gases during the firing of guns. In such cases a hardened layer from 0.05 to 0.08 mm. deep has been observed. The appearance of this layer, however, indicates that the temperature has not reached the Ac_3 point, although it has exceeded the Ac_1 ($723^\circ\text{C}.$) point.

Fig. 1 shows the depth of the hardened layer on a carbon steel shell after firing. This steel contained approximately 0.45% of carbon, 0.9% of manganese, 0.30% of silicon and 0.04% each of phosphorus and sulphur. Pearlite grains have been transformed into martensite, which is more resistant to etching than pearlite. As shown in Fig. 2 at a magnification of 1200 diameters, there is no transition zone between the martensite and pearlite. It is noticeable that ferrite grains persist up to the surface and are not dissolved in the austenite formed during heating. This shows that the Ac_3 point of this steel had not been exceeded.

Fig. 3 is another example which represents a section of a steel driving

* Received March 28, 1945.

band (carbon 0.27%, manganese 0.90%, silicon 0.06%, phosphorus and sulphur 0.02% each) attached to the shell described above. Martensite grains (white) are sharply distinguished from the ferritic background and pearlite grains (dark). Fig. 4 shows a single pearlite grain after shallow surface heating, *i.e.*, only a small part of the grain has been transformed into martensite. This particular grain is cut by a ferrite grain and is surrounded by others. It is evident that this intersecting ferrite grain remains unchanged—*i.e.*, sharply separated from martensite—up to the surface, confirming that during heating the A_{c3} point was not exceeded.

It can be seen from these micrographs that some of the pearlite grains have been only partially transformed into martensite grains and that the sharp boundary between the hardened layer and the parent material shows the depth to which the A_{c1} temperature penetrated.

The existence of the martensitic structure proves not only that the A_{c1} point was reached, but also that the cooling rate after heating was sufficiently rapid to cause a quenching effect from the A_{c1} temperature. The great bulk of the cold parent material underneath the heated zone, as well as the blast of cooling air shortly after emergence from the muzzle, provided the necessary quenching.

Finally, the ease with which the pearlite grains were transformed into martensite must be noted.

Further deductions have been based upon some simple experiments designed to produce local martensitic transformation.

It has been shown by Bowden and Hughes¹ that when one piece of metal slides over another the work done against friction appears as heat generated locally at many small points of contact between the two metal surfaces. Since these contact areas are very small, the temperature locally may temporarily reach quite a high value. The opinion has frequently been expressed that such high local temperatures actually reach the melting point. In the case of steel-to-steel friction, no evidence has been found to support such a view. On the other hand, owing to the heat developed locally, the metal can become sufficiently soft and plastic to yield to, or even be removed by, the pressure.

Let us consider some examples in which the heat developed by friction has been recorded in a natural way, *i.e.*, by structural changes in the material.

An ordinary hard steel (carbon 0.5%, manganese 0.8%) was cut with a hacksaw. After slight and careful polishing, micro-examination (Fig. 5) revealed distorted grains in the parent material. Fig. 6, an enlargement of part of Fig. 5, shows that some of the pearlite grains had been transformed into martensite. Similar effects were observed in this hard steel and in a soft (carbon 0.18%) steel when both were ground on a grinding wheel and then lightly polished (Figs. 7 and 8).

The above experiments show that friction can easily produce sufficient local heating to bring the surface temperature above the A_{c1} point, at which the pearlite changes into austenite, which, in turn, changes into martensite on rapid cooling. The cooling is naturally rapid, owing to the dissipation of the heat into the body of the metal and to the chilling effect of the cold air in contact with the surface. It may be noticed in this connection that Trent² has described a martensitic layer produced by the friction between adjacent wires in wire ropes.*

* Sir W. C. Roberts-Austen in a "Report of the Committee appointed by the Board of Trade to Enquire into the Loss of Strength in Steel Rails through Use on Railways," presented to both Houses of Parliament by Command of Her Majesty (London, 1900: H.M. Stationery Office), showed by micro-examination "the alteration of the surface of a rail by wear" and stated that "the lighter portion contains martensite, which shows that the rail had been locally hardened." That portion of material 0.01 in. in thickness represents a martensite with a net of ferrite (Fig. 3, Plate IV. of the Report).

If we consider the ease of the pearlite-martensite transformation and its resistance to further change, we are led to the conclusion that the martensite produced from pearlite is one of the most stable forms of this metastable phase. It is this quality which lends importance to steel of eutectoid composition.

(3) *Iron-Carbon Eutectoid Steel.*

The composition of the eutectoid has been variously fixed by different investigators. Bain³ and the "Metals Handbook" of the American Society for Metals give the composition as 0.8% of carbon. On the other hand, Carpenter and Robertson⁴ give the composition as 0.87% of carbon. There is evidence that neither of these values is quite correct.

Petch⁵ and Lipson and Parker⁶ proved that martensite has a tetragonal structure. Carpenter and Robertson⁴ stated that this structure is due to the modification of the cubic iron lattice by the inclusion of carbon atoms. Petch and Lipson and Parker showed that in the α -iron unit cell there are six available positions for the carbon atoms, of which, according to Petch, only one-twelfth are occupied. The tetragonality of a 1.57% carbon steel quenched from 1000° C. is given⁶ by $c/a = 1.066$, where $a = 2.847$ kX. and $c = 3.037$ kX. ($a = 2.8604$ kX. in ferrite). The mean value of the displacement of an iron atom in the α -iron lattice can, as stated by the above authors, alter with the carbon content.

When a hypereutectoid steel is quenched certain features are apparent. In order to bring into solution the whole of the free cementite, a higher temperature is needed than that required for eutectoid steel. The result of such heat-treatment is the retention of a certain amount of austenite with the martensite. This has been corroborated by the many authors quoted by Epstein,⁷ and is also evident in Fig. 9 (a), an X-ray picture of a rod of case-hardened mild steel (carbon 0.15%), heated to 900° C. for 10 hr. and then oil-quenched. The austenite lines A_3 , A_4 , A_8 , A_{11} , and A_{12} can be identified as well as the martensite lines M_2 , M_4 , M_6 , and M_8 . On the other hand, if the temperature is not raised sufficiently to bring all of the cementite into solution, this constituent should persist after quenching.

To simplify the identification of martensite and austenite lines in quenched steels, electrolytic iron and copper are shown in Figs. 9 (b) and 9 (c), respectively. The photographs were all taken using Co K_α radiation and an iron filter.

When austenite is present, even in traces, one can never be certain how much of the carbon remains in the austenite and how much has gone into the martensite. When, however, free cementite exists in a hypereutectoid steel quenched from exactly the A_{c_1} temperature, the martensite formed can contain only the amount of carbon associated with pearlite.

In the case of steel of hypo-eutectoid composition, where the temperature has not reached A_{c_3} an excess of ferrite will be present. Such is the case in the mild-steel driving band described above. If the A_{c_3} temperature had been exceeded, it would have been difficult for the austenite to have changed into martensite without the precipitation of ferrite. Such conditions generally reveal themselves by the presence of bainite as well as martensite, i.e., by showing Ar_1' and Ar_1'' transformations.

The above argument suggests that a "true" martensite should be expected in quenched plain carbon eutectoid steel. The pearlite grains transformed into martensite in the steels described above are an example of this.

A further experiment was made. A rod was cut from the transition zone (showing ferrite and martensite) of a specimen of case-hardened mild steel (carbon 0.15%) which had been heated to 900° C. for 10 hr. and then oil-quenched. X-ray pictures were taken of the rod to see whether

they indicated the presence of the two structural components. Fig. 10 (a) shows the result of this experiment. For comparison, Fig. 10 (b) illustrates the result obtained with a rod taken from the centre of the same mild-steel specimen. In (a) the lines are all broader than those in (b), and, further, in (a) the low-angle line 110 is a doublet. The second line of this doublet is due to ferrite and the first to the quenched component (austenite).^{*} More detailed consideration of this point will be published in due course.

As shown in Fig. 3, the surface layer of the mild-steel band consists of martensite embedded in ferrite. A very thin flake was cut from the surface of the band and carefully ground, in the hope that all of the parent

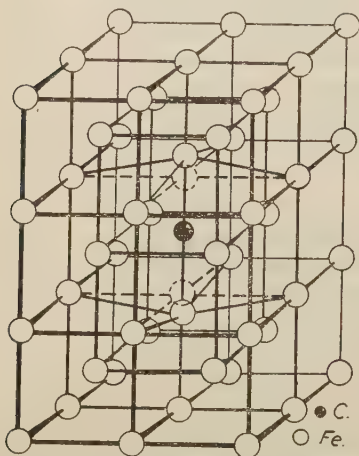


FIG. 11.—Atomic Arrangement in Martensite in Eutectoid Steel. One carbon atom distorts twelve α -iron unit cells. For clarity only two displaced iron atoms shown.

See *Journal of The Iron and Steel Institute*, 1944, No. I., p. 137 P, Figs. A and B.)

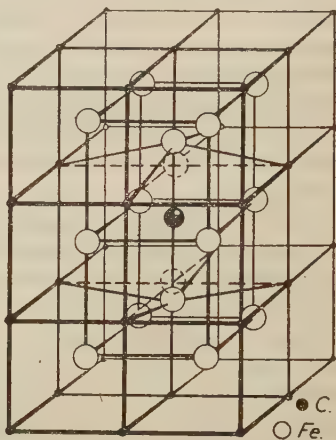


FIG. 12.—Simplified Drawing of Fig. 11 (iron atoms at corners indicated by dots), showing displacement of iron atoms and that the carbon atom on one edge of the first set of simple cubes must be regarded as situated in the face of the second set of simple cubes.

material would be removed. Fig. 10 (c) is an X-ray picture of this flake, whilst Fig. 10 (d) is a picture of the parent material inside the band. The similarity of Figs. 10 (c) and (d) to Figs. 10 (a) and (b) is most marked, although the doublet in (a) is not distinctly resolved in (c). There is thus a certain amount of quantitative evidence that the presence of martensite grains can be detected by X-ray examination.

A calculation⁸ of the number of carbon and iron atoms involved shows that in the martensite formed in a eutectoid steel, one single carbon atom is situated among 12 unit cells of iron, which suggests a eutectoid composition of 0.888% C.[†] That appears to be the most probable pearlite composition in plain carbon steel. One carbon atom inserted among the 12 unit cells of iron must distort them, because there are no interstices large enough to accommodate a carbon atom of radius 0.77 Å. without the displacement of neighbouring atoms.

^{*} Ferrite, 110 line; austenite, 111 line.

[†] Carbon, % = $\frac{100 \times 12.01}{24 \times 55.84 + 12.01} = 0.88820\%$.

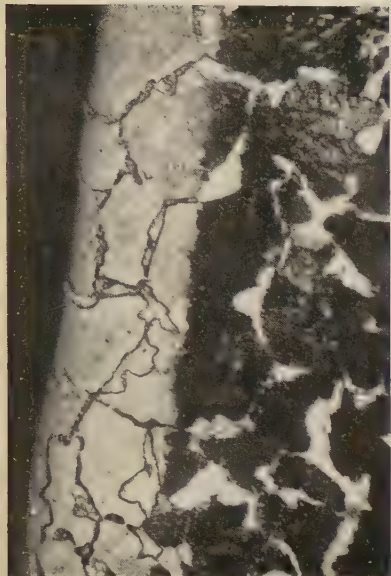


FIG. 1.—Depth of Hardened Layer on 0.45% Carbon Steel Shell after Firing. $\times 200$.



FIG. 2.—Martensite/Pearlite Boundary in Fig. 1 at higher magnification. $\times 1200$.



FIG. 3.—0.27% Carbon Steel Driving Band: martensite (white) sharply distinguished from ferritic background and pearlite grains (black). $\times 500$.

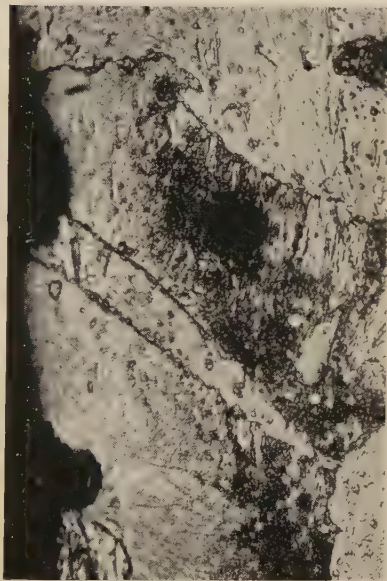


FIG. 4.—Single Pearlite Grain after Shallow Surface Heating (small part transformed to martensite). Grain cut by ferrite. $\times 1200$.

FIGS. 1 to 4.—Etched with Nital

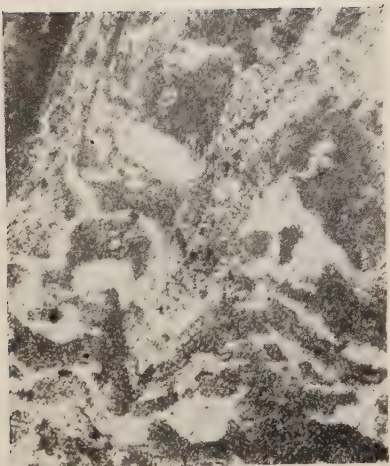


FIG. 5.— $\times 180$.

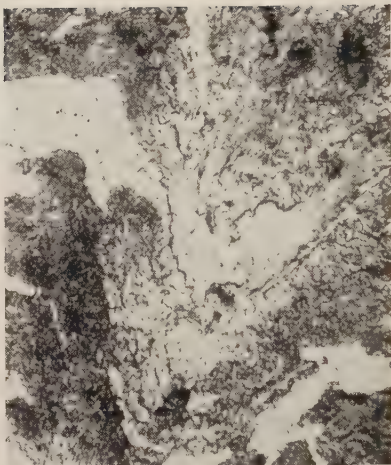


FIG. 6.— $\times 600$.

FIGS. 5 and 6.—0.5% Carbon Steel cut with a Hacksaw.

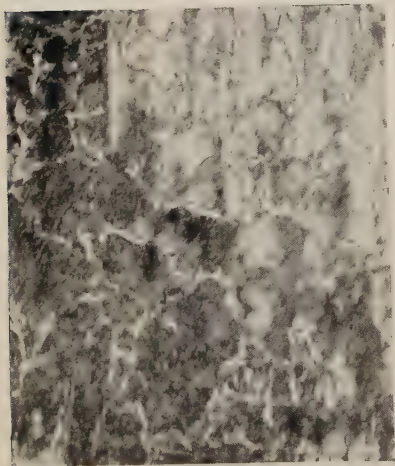


FIG. 7.—0.5% Carbon Steel, after grinding $\times 150$.



FIG. 8.—0.18% Carbon Steel, after grinding. $\times 600$.

FIGS. 5 to 8.—Pearlite Grains Transformed into Martensite. Etched with Nital.

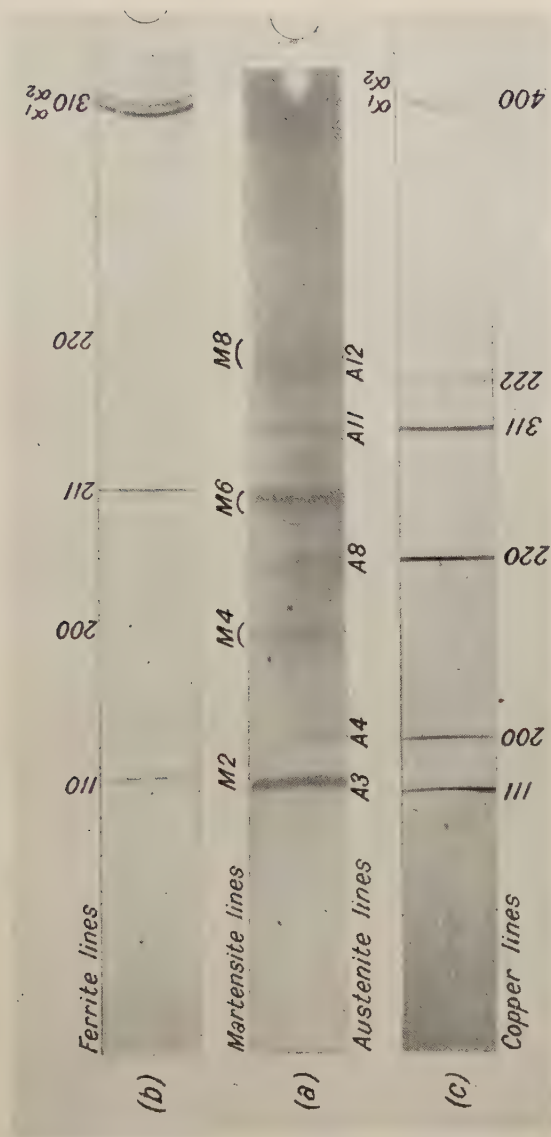


FIG. 9.—X-Ray Films; 9-cm. camera, Co K α radiation, iron filter. (a) Case-hardened steel oil-quenched from 900° C. (b) Electrolytic iron. (c) Electrolytic copper.

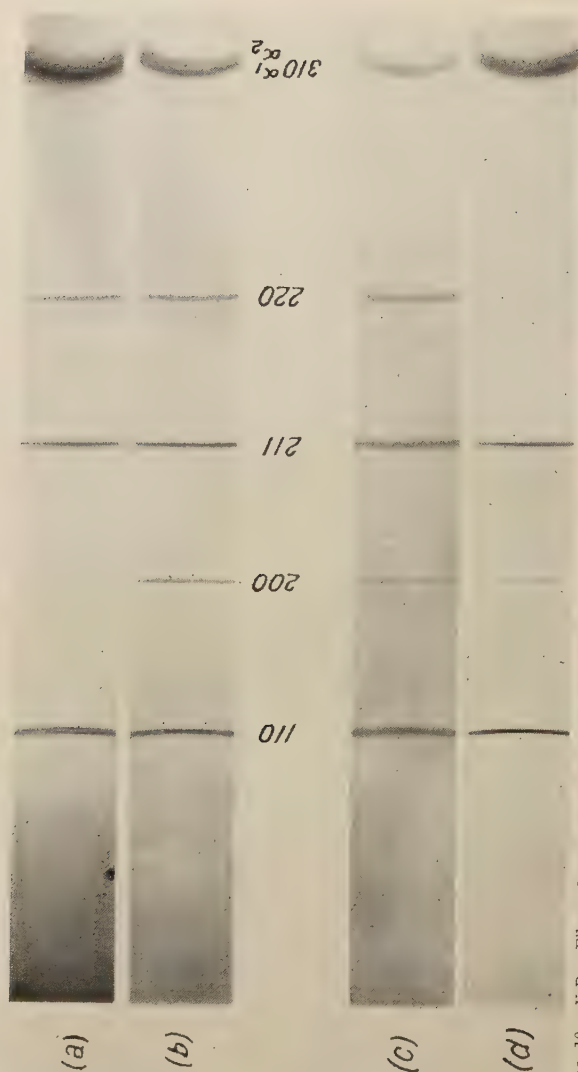


FIG. 10.—X-Ray Films; 9-cm. camera, $\text{Co } K\alpha$ radiation, iron filter. (a) Transition zone, (b) centre, of a case-hardened steel oil-quenched from 900°C . (c) Surface layer, (d) parent metal, of the mild-steel band (see Fig. 3).

If the above argument is correct, then the atomic arrangement in martensite in a eutectoid steel may be represented by Fig. 11. Although in reality all of the iron atoms are displaced, only two are so shown for the sake of clarity. Fig. 12, a simplified version of Fig. 11, shows that the carbon atom at one edge of the first set of simple cubes must be regarded as situated in the face of the second set of cubes. The symmetrical position of the single carbon atom in martensite in a eutectoid steel provides an explanation for the fact that the excess of carbon in a hypereutectoid steel tends to precipitate easily in the form of free cementite. This is not the case, however, when the excess of carbon can be retained in austenite residues, which can easily accommodate more carbon atoms (up to 0.32 atoms per unit cell in saturated solid solution ⁵) than martensite.

Such a condition of symmetry, in which the carbon atom is surrounded by an octahedron of iron atoms, probably explains the stability of the metastable martensitic phase. It also probably explains why, in the mild-steel driving band and in plain carbon steels subjected to friction, the pearlite grains, transformed into austenite, can so easily produce the structure of martensite.

One is therefore probably justified in saying that martensite formed from pearlitic steel represents an ideal form, or, perhaps, the only possible form of perfect martensite.

Acknowledgments.

The author tenders his best thanks to Professor N. F. Mott, F.R.S., for permission to publish this paper, to Professor C. W. Dannatt for the provision of laboratory facilities, and to Dr. J. F. Allen for his valuable help; he also wishes to thank all of them for valuable criticism and discussion.

REFERENCES.

1. F. P. BOWDEN and T. P. HUGHES: "The Surface Temperature of Sliding Metals and its Influence on Surface Flow and Wear," International Association for Testing Materials, London Congress, 1937, p. 176.
2. E. M. TRENT: *Journal of The Iron and Steel Institute*, 1941, No. I., p. 401 P.
3. E. C. BAIN: "Function of the Alloying Elements in Steel." Cleveland, Ohio, 1939: American Society for Metals. In the Third Printing, 1943, pp. 20-22, the author refers to the results obtained by R. F. Mehl and C. Wells, *American Institute of Mining and Metallurgical Engineers*, 1937, Technical Publication No. 798: *Metals Technology*, 1937, vol. 4, No. 4.
4. SIR HAROLD CARPENTER and J. M. ROBERTSON: "Metals," vol. II. London, New York and Toronto, 1939: Oxford University Press.
5. N. J. PETCH: *Journal of The Iron and Steel Institute*, 1943, No. I., p. 221 P.
6. H. LIPSON and AUDREY M. PARKER: *Journal of The Iron and Steel Institute*, 1944, No. I., p. 123 P.
7. S. EPSTEIN: "The Alloys of Iron and Carbon," vol. I., "Constitution." New York, 1936: McGraw-Hill Book Co., Inc.
8. W. J. WRAŻEJ: *Journal of The Iron and Steel Institute*, 1944, No. I., p. 135 P.

THE SUBSTITUTION OF BLACKPLATE FOR TINPLATE IN CANS FOR FRUIT AND VEGETABLES.*

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SYNOPSIS.

A study has been made of the effect of substituting lacquered blackplate ends for tinsplate ends in fruit and vegetable cans. The points noted were the rate of formation of hydrogen in the cans, the rate of dissolution of iron and tin, and the effect of the substitution on the colour and flavour of the contents. The main conclusions reached were as follows :

(1) Cold-reduced plate is superior to hot-rolled plate on blackplate ends covered with a single roller-coating of lacquer. Phosphating does not reduce the rate of internal corrosion and may increase it if the lacquer adheres indifferently to the surface of the plate.

(2) Types of lacquer vary in the protection they afford. Lacquered blackplate ends, with a further dipped coating of lacquer, give results which are comparable with standard lacquered or plain tinsplate ends.

(3) The rates of attack of the various fruits and vegetables on blackplate ends differ greatly and are highest for the acid fruits and beetroot.

(4) The substitution of blackplate for tinsplate ends does not affect the colour and flavour of vegetables if the lacquer protection is of average efficiency. The situation is much less satisfactory with fruits.

(5) The substitution of blackplate for the bodies of cans as well as the ends is impracticable for general use, but the effect on the storage properties is very similar to that observed in cans with tinsplate bodies and blackplate ends.

In these tests the weight of the lacquer film on the phosphated plate was the same as that on the untreated blackplate. Better results were obtained when heavier films were used with phosphated plate.

THE loss of the main source of supply of tin early in 1942 made it necessary to seek methods of economizing in the use of tinsplate in the canning industry, and the work described in this paper forms part of a wider investigation undertaken at that time. Difficulties associated with the soldering of the side seams of blackplate cans make it impracticable to substitute blackplate for tinsplate over the entire can, and so the present study was confined very largely to the possibility of using blackplate ends in place of tinsplate ones. Even this partial substitution results, however, in a saving of tin amounting to 35-40% for the small and medium sizes of cans commonly used for vegetables and fruits.

Earlier experiments on the use of blackplate cans have been described by Kohman and Sanborn,¹ Lueck,² and Mantell and Lincoln;³ these studies were very limited in scope and were not pursued further as there was no pressing need to economize in tin when the tests were made. Piegai,⁴ Weise,⁵ and Jakobsen⁶ have recently recommended a limited use of cans with blackplate ends for non-corrosive products, and experiments made with artificial test solutions have been described by Edsäter.⁷ The most extensive and valuable of recent work is that of Lueck and Brighton,⁸ who have shown that cans with lacquered, phosphated steel ends are satisfactory for lima beans, peas, corn, meat, and some marine products:

* Received March 14, 1945.

DESIGN OF EXPERIMENTS.

The types of plate, methods of lacquer protection, and compositions of the steel of the can ends tested in the present investigation are set out in Table I. Where blackplate ends were used the tinplate bodies were all made from cold-reduced steel; where the ends were of tinplate the bodies were made from the same batch of plates as the ends. The main experiments on vegetables fall into two groups (tests *A* and *B*) and those on fruits into one group. The factors examined in test *A* were the type of plate used (hot-rolled and cold-reduced) and the type of lacquer protection (two different lacquers applied as a single roller-coating or as a dipped coating over a single roller-coating), the various lots with blackplate ends being compared with normal tinplate controls. The factors examined in test *B* were the type of plate used (phosphated blackplate as well as ordinary blackplate) and the type of lacquer protection (various coatings). After the best practical substitute for tinplate ends had been ascertained from tests *A* and *B*, a further series of experiments was undertaken (test *C*) in which six lots of each vegetable, representing different varieties and soils, were tested in these cans to determine the variability in corrosive properties of each of the common vegetables. The experiments with fruits (test *D*) included tests on cold-reduced blackplate and phosphated blackplate and on two methods of lacquering, comparison being made with controls of hot-rolled and cold-reduced tinplate. A further small experiment on fruits and vegetables was made with cans composed entirely of blackplate.

EXPERIMENTAL TECHNIQUE.

(a) *Canning.*

Standard methods were used in preparing and processing the various fruits and vegetables, special attention being given to the conditions under which the cans were closed, so as to ensure uniformity of headspace and vacuum within each batch. The cans used were the *A1* tall size (nominal capacity 16.9 oz.), and the average final vacua were 9–14 in. in the various lots. Full details of the canning technique have been given elsewhere by the present authors.⁹

(b) *Storage.*

Most of the cans, after processing and closing, were transferred to a constant-temperature store at 35° C., and the remainder were stored at normal temperatures.

(c) *Examination of Cans.*

One of the chief risks in substituting lacquered blackplate for tinplate is an increase in the rate of formation of hydrogen in the cans. The rate of corrosion of tinplate cans filled with vegetables is very slow compared with that of cans filled with fruits, and so it was necessary to use different experimental techniques for the two classes of products. With fruits the cans were merely held in store until the evolution of hydrogen overcame the partial vacuum initially present and then built up sufficient pressure for the cans to dome outwards and become "hydrogen swells." Results of comparative tests on fruits were generally ready after 6–12 months' storage. The slower formation of hydrogen in canned vegetables made it necessary to measure very small reductions of vacuum in the sealed cans. This was done by recording the average change in depression of the centre of the ends below the level of the horizontal channel adjacent to the end seams. The measurement was made by means of a specially constructed spherometer on blocks of 8–12 cans of each lot and repeated at monthly intervals. The method has been described elsewhere by

TABLE I.—*Composition of Steel in Test Cans.*

Lot No.	Type of Plate on Ends. ^{1a}	Lacquering of Ends.	Composition of Steel Base. %.					
			C.	S.	P.	Mn.	Cu.	Ni.
1	<i>Vegetables A.</i>		0.122	0.061	0.060	0.37	0.059	0.117
2	Blackplate, hot-rolled	Single roller coat, S.R. lacquer						
5	" "	" " meat lacquer	0.106	0.037	0.038	0.34	0.021	0.029
6	" "	Dipped, meat lacquer on S.R. lacquer						
3	" "	" " on meat lacquer	0.102	0.048	0.041	0.35	0.034	0.034
4	cold-reduced	Single roller coat, S.R. lacquer						
7	" "	" " meat lacquer	0.123	0.069	0.083	0.38	0.068	0.070
8	" "	Dipped, meat lacquer on S.R. lacquer						
9a	" "	" " on meat lacquer	0.106	0.039	0.033	0.36	0.014	0.055
9b	Tinplate, cold-reduced	Single roller coat, S.R. lacquer						
	<i>Vegetables B.</i>		0.114	0.038	0.039	0.38	0.012	0.081
10	Blackplate, cold-reduced	Plain						
11	" "	Dipped, meat lacquer on meat lacquer	0.103	0.035	0.024	0.37	0.010	0.032
12	" "	Single roller coat, meat lacquer						
13	" "	Double roller coat, S.R. on S.R.	0.111	0.035	0.018	0.35	0.020	0.046
14	" "	" " meat on S.R.						
15	" "	" " meat on S.R. (U)	0.119	0.062	0.065	0.37	0.045	0.042
16	Phosphated blackplate, cold-reduced	Single roller coat, S.R. lacquer						
17a	" "	" " S.R. lacquer	0.114	0.039	0.039	0.38	0.012	0.081
17b	Tinplate, cold-reduced	Single roller coat, S.R. lacquer						
	<i>Vegetables O.</i>		0.111	0.035	0.018	0.35	0.020	0.046
18	Blackplate, cold-reduced	Double roller coat, meat on S.R.						
19a	Tinplate, cold-reduced	Single roller coat, S.R.	0.119	0.062	0.065	0.37	0.045	0.042
19b	" "	Plain						
20	<i>Fruits.</i>		0.107	0.023	0.034	0.30	0.012	0.040
21	Blackplate, cold-reduced	Double roller coat, fruit lacquer						
22	" "	Dipped, on single roller coat, fruit lacquer	0.104	0.031	0.025	0.33	0.014	0.038
23	Phosphated blackplate, cold-reduced	Double roller coat, fruit lacquer						
24	Tinplate, cold-reduced	" " or plain	0.101	0.036	0.041	0.31	0.015	0.040
	" "	" "						
	" "	" "	0.115	0.071	0.062	0.36	0.030	0.059
	" "	" "						

* In all blackplate tests the tinplate bodies were of cold-reduced plate; only the hot-rolled tinplate controls had hot-rolled plate for the bodies (i.e., No. 9b, 17b, 19b, 24).

S.R. (U) = Sulphur-resisting lacquer, unpigmented.
Fruit = Fruit lacquer (copal type).

S.R. = Sulphur-resisting lacquer.
Meat = Meat lacquer (synthetic).

Adam¹⁰ and is capable of detecting a fall in vacuum of half an inch. By this means it was possible to detect significant differences between lots which had been stored for only 1-6 months, whereas about ten times this storage period would have been required to produce hydrogen swells. Other cans were opened periodically, and the proportion of the surface of the blackplate ends visibly corroded was noted.

(d) *Examination of Contents.*

Cans from lots No. 1, 2, 5, 6, 9, 10, 11, 16, 17, 20, 21, 22, and 23 (see Table I.) were withdrawn, and the headspace gases analysed for hydrogen, oxygen, and carbon dioxide after 1, 4, 13, 26, and 52 weeks' storage. The contents were analysed for iron, and their appearance and flavour noted. Analyses were made on duplicate cans in all cases.

EXPERIMENTAL RESULTS.

Test A.—Vegetables.

(a) *Factors Tested.*

Eight lots of cans with blackplate ends and two lots of tinplate controls were included in this test. Lacquered tinplate bodies were used for the cans of processed peas and beetroot, and plain bodies for the cans of the other vegetables. Details of the plates and lacquers are shown in Table I.

(b) *Loss of Vacuum.*

The rate of fall of vacuum in the cans stored at 35° C., as recorded by spherometer readings on groups of 12 cans of each lot, was found to be virtually constant in each of the lots tested. This indicated that the production of hydrogen was fairly uniform over the period when there was still a partial vacuum in the cans. The rates of fall are given in Table II.,

TABLE II.—Rate of Loss of Vacuum (In. per Month at 35° C.) in Test A.

Vegetable.	Single Lacquer.				Dipped on Single Lacquer.				Tin-plate Control.
	Hot-Rolled.		Cold-Reduced.		Hot-Rolled.		Cold-Reduced.		
	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.		No. 9.
Processed peas . . .	0.40	0.74	0.31	0.33	0.23	0.18	0.26	0.20	0.21 *
Beetroot	3.8	4.4	2.0	3.0	(3.2) †	(2.7) †	(2.0) †	(2.2) †	(1.8) * †
Carrots	0.21	0.29	0.21	0.33	0.08	0.14	0.16	0.10	0.10 †
Parsnips	(0.70) †	(0.75) †	0.21	0.24	0.26	0.28	0.15	0.24	0.12 †
Beans in tomato sauce .	0.43	0.74	0.26	0.54	0.16	0.22	0.21	0.16	0.14 †
Swedes	0.58	1.20	0.47	0.93	0.48	0.56	0.54	0.54	0.55 †
Beans in brine . . . .	...	...	0.28	0.21	...	...	0.16	0.18	0.25 †

* Cans with lacquered tinplate bodies were used (lot 9a).

† Cans with plain bodies were used (lot 9b).

‡ The rates shown in brackets were not constant, but increased slightly with time of storage; average rates are given in these cases.

and subsequent prolonged storage of the cans has shown that hydrogen swells are developing at proportional rates which are in close agreement with the figures in this table. In the cans with blackplate ends the superiority of cold-reduced over hot-rolled plate is evident in the lots with a single roller-coating of lacquer. In the cans which had had a dipped coating of lacquer applied after the roller-coated ends had been stamped out, the difference between the two types of plate was much less marked. This is not surprising, as the ends were almost completely protected with the result that most of the corrosion occurred on the side seams. In this

respect they were quite comparable with the tinsplate controls. Unfortunately there are practical difficulties in dipping ends in lacquer in large-scale production, and the best results that can be expected are somewhere between the relatively poor performance of the single-lacquered ends and the excellent performance of the dipped ends.

The poorer behaviour of the hot-rolled, compared with the cold-reduced blackplate ends may be partially accounted for by the fact, noted by Dickinson,¹¹ that the coupling of hot-rolled ends to cold-reduced bodies results in severe anodic corrosion of the former. This tendency to throw the corrosion on to the ends makes it all the more necessary that blackplate ends should have adequate lacquer protection.

(c) *Hydrogen Swells and Composition of Headspace Gases.*

Most of the cans in this test have been stored at 35° C. for nearly three years and a high proportion of some of the lots are now hydrogen swells. The full figures are not given, as they correspond closely with the rates of loss of vacuum shown in Table II. At one extreme, 25% of the single-lacquered cans of beetroot became hydrogen swells in 15 weeks, a similar proportion of the cans with dipped ends after 22 weeks, and the tinsplate controls after 26 weeks; at the other extreme, none of the cans of carrots or beans in brine, and none of the processed peas except lot No. 2, have yet become hydrogen swells. The hydrogen content of the headspace gases, as determined at frequent intervals during the early stages of storage at 35° C., gave a clear indication of the relative rates of corrosion, and the figures agreed closely with the rates of loss of vacuum shown in Table II. In the cans with plain bodies the original oxygen had virtually disappeared after one week's storage at 35° C.; in the cans with lacquered bodies the loss of oxygen was equally rapid when single-lacquered blackplate ends were used and a little slower in the cans with dipped ends and in the tinsplate controls.

(d) *Amount of Iron and Tin in Contents.*

Metallic contamination of the contents is important from a health standpoint and from the tendency of tin or iron to cause discoloration in some vegetables. It is also a useful indication of the type of corrosion which has occurred. The iron content of the vegetables after various periods of storage at 35° C. is given in Table III.

TABLE III.—*Iron Content (Parts per Million) of Vegetables Stored at 35° C. for One, Four, Thirteen, and Twenty-Six Weeks, Test A.*

Vegetable.	Single Roller Coat.		One Coat Dipped Lacquer over Single Roller Coat.		Tinsplate Control, No. 9.
	S.R. Lacquer, No. 1.	"Meat" Lacquer, No. 2.	S.R. Lacquer, No. 7.	"Meat" Lacquer, No. 8.	
Processed peas . . .	6, 8, 17, 17	8, 12, 29, 32	6, 7, 13, 15	7, 7, 14, 15	..., 6, 13, 16*
Beetroot . . .	10, 19, 59, 136	12, 43, 62, 166	6, 13, 38, 90	..., 12, 38, 99	7, 8, 45, 80*
Carrots . . .	4, 8, 9, 12	7, 14, 14, 14	3, 6, 8, 9	2, 4, 6, 6	3, 7, 9, 8†
Parsnips . . .	..., 7, 8, 13	..., 10, 12, 15	..., 5, 9, 8	4, 6, 12, 8	4, 6, ..., 8†
Beans in tomato sauce .	14, 13, 21, 14	15, 12, 16, 10	12, 15, 15, 10	14, 14, 12, 11	14, 16, 11, 10†

* Cans with lacquered tinsplate bodies were used (lot 9a).

† Cans with plain bodies were used (lot 9b).

It will be seen that the iron content of nearly all lots except beans in tomato sauce increased appreciably up to 26 weeks' storage; the rate of

increase in canned beetroot was very rapid, and lot No. 2 (which is also the worst in Table II.) had the heaviest contamination.

The tin content of the canned beetroot and beans in tomato sauce was determined after six months' storage at 35° C. It was 19-25 p.p.m. in the canned beetroot and 150-230 p.p.m. in the canned beans. The tin content of canned vegetables stored at normal temperatures is shown in Table IV.

TABLE IV.—*Iron and Tin Content (Parts per Million) of Vegetables Stored at Normal Temperatures, Test A.*

Vegetable.	Storage Period. Months.	Iron Content.			Tin Content.		
		Single Lacquer, No. 1 and 2.	Dipped Lacquer, No. 7 and 8.	Tinplate Control, No. 9.	Single Lacquer, No. 1 and 2.	Dipped Lacquer, No. 7 and 8.	Tinplate Control, No. 9.
Processed peas (I.)	8	14	11	8 *	21	22	20 *
" " (II.)	33	45	29	20 *	Trace	Trace	Trace *
Beetroot . . .	5	...	...	...	10	19	21 *
Carrots . . .	9	20	14	7 †	117	101	148 †
Parsnips . . .	11	...	...	...	82	91	95 †
Swedes . . .	34	31	19	20 †	33	31	60 †
Beans in tomato sauce . . .	18	...	...	...	214	175	156 †

* Cans with lacquered tinplate bodies were used (lot 9a).

† Cans with plain bodies were used (lot 9b).

From the figures in Tables III. and IV. it is evident that corrosion took a very different course in the canned beetroot and beans in tomato sauce. In the former there was hardly any dissolution of tin and corrosion was confined almost entirely to the steel. Calculations showed that the volume of hydrogen in the headspace of cans of beetroot which had not yet developed a positive pressure was virtually the equivalent of the iron dissolved in the contents. In the canned beans in tomato sauce, on the other hand, there was no dissolution of iron, which indicates that the steel must have been entirely cathodic. No simple relationship existed in this case between the tin content and the volume of hydrogen evolved, as much of the tin present had been stripped from the plate through the action of the oxygen initially present in the can.

Table IV. shows clearly that the contents of the cans with single-lacquered ends contained more iron than those with dipped ends. The contents of cans with lacquered bodies (*i.e.*, peas and beetroot) tended to have a low tin content associated with a relatively high iron content, and those with plain bodies had a high tin content coupled with a low iron content. There was one exception in the case of swedes (and this has been confirmed in several other tests), where the tin content was lower and the iron content higher than might have been expected in plain cans. This was apparently due to the formation of a sulphide film on the surface of the metal, which partially protected the tin from corrosion and thereby caused increased corrosion of the iron.

These tests also show that the iron contents of vegetables packed in cans with blackplate ends protected by an efficient lacquer film are not appreciably different from those of cans with tinplate ends. The tin contents appear to be independent of the efficiency of lacquering of the blackplate ends.

(e) *Visible Internal Corrosion of Cans.*

Dark grey or brown patches appeared on the inner surface of the top ends of some of the blackplate cans. These patches consisted of clusters of small blisters in the lacquer with rust spots below, and had been formed during processing or in the early days of storage. In the cans held at normal temperatures the area covered by these patches increased gradually in nearly all packs over the two years in which the cans were stored. The amount of internal blistering and rusting of the ends did not bear any direct relationship to the loss of vacuum, but the single-lacquered ends were more seriously affected than the dipped ends. Loose black deposits of iron sulphide were noted on several cans of peas, swedes, and carrots which had been stored for two years, but neither these deposits nor the rust patches were sufficiently unsightly to make the cans unmarketable.

(f) *Appearance and Flavour.*

The use of blackplate in place of tinplate ends did not affect the colour of the vegetables appreciably, except in so far as the beetroots discoloured in proportion to their iron content. Specks of iron sulphide were noted in some of the cans of peas, swedes, and carrots, particularly in those with single-lacquered ends. Apart from a metallic flavour in the beetroot with a high iron content, there was no apparent difference in flavour between the vegetables from blackplate and those from tinplate cans.

Test B.—Vegetables.(a) *Factors Tested.*

This test was carried out to compare phosphated blackplate with standard blackplate, and various double roller-coatings of lacquer with single roller-coatings and dipped coatings. The seven lots of blackplate ends and the two tinplate controls are described in Table I. Peas, stringless beans, and beetroot were packed in cans with lacquered tinplate bodies, and carrots, potatoes, turnips, and beans in tomato sauce in cans with plain tinplate bodies.

(b) *Loss of Vacuum.*

The rate of fall of vacuum is given in Table V.

TABLE V.—*Rate of Loss of Vacuum (In. per Month at 35° C.), Test B.*

Vegetable.	Blackplate.					Phosphated.		Tinplate.
	No. 10.	No. 11.	No. 12.	No. 13.	No. 14.	No. 15.	No. 16.	No. 17.
Fresh peas . . .	0.28	0.26	0.38	0.30	0.26	0.22	0.25	0.30 *
Processed peas . . .	0.10	0.12	0.09	0.11	0.11	...	...	0.09 *
Stringless beans . . .	0.36	...	...	...	...	1.00	0.70	0.76 *
Beetroot . . .	1.82	2.30	1.60	0.84	1.60	1.39	0.95	1.53 *
Carrots . . .	0.27	...	...	...	...	0.30	0.21	0.10 †
Potatoes . . .	0.11	0.45	0.10	0.10	0.10	0.56	0.17	0.11 †
Turnips . . .	0.20	0.47	0.19	0.20	0.24	0.80	0.25	0.25 †
Beans in tomato sauce.	0.25	0.40	0.27	0.37	0.32	1.17	0.24	0.24 †

* Cans with lacquered bodies were used (lot 17a).

† Cans with plain bodies were used (lot 17b).

The ends made of standard blackplate were all remarkably good. The cans with single roller-coated ends (No. 11) were a little less satisfactory than those with double roller-coated or dipped ends (No. 10, 12, 13, and 14), and the latter were quite as good as the tinplate controls (No. 17).

The phosphated ends covered with a single coating of S.R. lacquer (No. 16) also gave as good results as the tinplate controls, but the phosphated ends covered with a single coating of meat lacquer (No. 15) were definitely inferior, and were the least satisfactory of any of the ends tested. Subsequently hydrogen swells developed at rates in close agreement with those to be expected from Table V.

Test C.—Vegetables.

(a) Factors Tested.

The natural variability of corrosive properties of the common vegetables was tested using tinplate cans and cans with blackplate ends covered with a double roller-coating of meat lacquer on S.R. lacquer. Cans with lacquered tinplate bodies were used for processed peas and beetroot, and cans with plain tinplate bodies for carrots, potatoes, and beans in tomato sauce.

(b) Loss of Vacuum.

The rate of corrosion was again determined by the rate of loss of vacuum at 35° C., and the results are shown in Table VI. The figures in the third column show the number of lots of each vegetable tested. The effect of the natural variation in corrosive properties of most vegetables produced greater differences in rate of loss of vacuum than the substitution of blackplate for tinplate.

TABLE VI.—Rate of Loss of Vacuum (In. per Month at 35° C.), Test C.

Vegetable.	Ends.	No. of Samples.	Range of Rate of Loss of Vacuum.
Processed peas	Blackplate No. 18	6	0.2 -0.7
" " " " " "	Tinplate No. 19a	6	0.1 -0.2
Beetroot	Blackplate No. 18	6	1.4 >15
" " " " " "	Tinplate No. 19a	6	0.2 -2.0
Carrots	Blackplate No. 18	4	0.1 -0.9
" " " " " "	Tinplate No. 19b	4	0.03-0.3
Potatoes	Blackplate No. 18	6	0.4 -1.8
" " " " " "	Tinplate No. 19b	6	0.1 -0.5
Beans in tomato sauce	Blackplate No. 18	6	0.6 -1.3
" " " " " "	Tinplate No. 19b	6	0.2 -0.5

As a loss of 10-12 in. of vacuum may result in the production of hydrogen swells in an appreciable proportion of a canner's pack, there should not be a greater rate of loss than about 1 in. per month if the cans are to survive a year's storage. On this assumption it is evident from Table VI. that blackplate ends are unsatisfactory for canned beetroot, and possibly for canned potatoes and beans in tomato sauce, stored at tropical temperatures. They are also unsatisfactory for canned beetroot stored at normal temperatures, where the rates of loss of vacuum would be about one-third to one-quarter of those shown in Table VI. Corrosion tests made in the laboratory on steel strips immersed in beetroot juice bear out the results of the canning tests in showing that beetroots must be classed with fruits rather than with vegetables as regards their corrosive properties.

Test D.—Fruits.

(a) Factors Tested.

Two lots of ordinary blackplate—one covered with a double roller-coating of lacquer and the other with a dipped coating over a single roller-

coating of lacquer—were compared with phosphated blackplate covered with a double roller-coating of lacquer. Tinplate controls were of hot-rolled and cold-reduced plate. Rhubarb, loganberries, blackberries, red plums, and damsons were packed in cans with double-lacquered bodies, and gooseberries, white cherries, and golden plums in cans with plain bodies. Details of the cans used are given in Table I.

(b) *Visible Corrosion.*

With most fruits the bottom ends of double roller-coated blackplate and phosphated plate (Nos. 20 and 22) were badly attacked and corroded, the corrosion being visible after one week's storage at 35° C. The cans with dipped blackplate ends (No. 21) were comparable with the tinplate controls and, for rhubarb, were better than the controls.

(c) *Hydrogen Swells.*

The rates of formation of hydrogen swells in the various lots are shown in Table VII., where they are expressed as the time taken for 25% of the cans to reach this condition. Double roller-coated blackplate and phosphated ends (Nos. 20 and 22) were found to be most unsatisfactory for all fruits in lacquered cans. The fact that the difference between the blackplate and the tinplate ends was less marked in the cans with plain bodies was due to the inhibitory action of the dissolved tin and the anodic protection afforded the steel by the large area of tin exposed. The dipped ends (No. 21) were comparable with the tinplate controls in most cases, and the cold-reduced tinplate gave decidedly better results than the hot-rolled tinplate.

TABLE VII.—*Time Required (Weeks) to Produce 25% Hydrogen Swells in Fruits.*

Fruit.	Body.	Blackplate.		Phosphated.	Tinplate.	
		Roller Lacquered, No. 20.	Dipped Lacquer, No. 21.	Roller Lacquered, No. 22.	Cold-Reduced, No. 23.	Hot-Rolled, No. 24.
Rhubarb . . .	Lacquered	21	60	...	97	92
Loganberries . . .	"	5	44	5	66	30
Blackberries . . .	"	7	51	16	97	30
Red plums . . .	"	5	33	4	55	61
Damsons . . .	"	6	42	5	56	42
Gooseberries . . .	Plain	39	66	31	106	105
White cherries . . .	"	54	104	44	104	69
Golden plums . . .	"	26	53	18	102	90

There is sufficient evidence to show that the governing factor in the corrosion of fruit cans, whether lacquered or plain, is the area of iron exposed. In the case of lacquered cans the corrosion is almost entirely confined to the iron, and is consequently proportional to the area of the baseplate exposed. In plain cans most of the corrosion is produced through the action of the tin-iron couple, and the limiting factor in this case is the available area of cathodic iron. Hence completely protected blackplate ends might be expected to give better results than normal tinplate ends, which have some iron exposed, and it is obvious, therefore, that even the dipped blackplate ends in the present tests were not perfectly protected. Some fracturing of the lacquer must have occurred during seaming. The roller-coated blackplate ends had suffered severe additional

damage during the process of stamping out and consequently gave much more trouble from corrosion.

(d) *Colour and Flavour of Contents.*

Discoloration of red or purple fruits, accompanied by metallic flavours, was noticeable in the cans with roller-coated blackplate or phosphated ends. Apart from these obvious defects, which increased with the extent of corrosion, there were no abnormal characteristics of the fruits packed in blackplate cans, except possibly a rather milder flavour.

CANS MADE ENTIRELY OF BLACKPLATE.

Factors Tested.

The cans used for these tests were made entirely from hot-rolled or cold-reduced blackplate and had to be soldered along the side seam after closure. For the tests on peas, carrots, and potatoes, the cans were lacquered with a single roller-coating of S.R. lacquer; a double roller-coating of fruit lacquer was used for the tests on damsons and blackberries.

Experimental Results.

The loss of vacuum during the early stages of storage of the canned vegetables was more rapid than tests *A*, *B*, and *C*, where the ends only were of blackplate, but the average rate of loss over two years' storage at 35° C. was very little more than the rates shown in Table VI. The rates for the hot-rolled cans were: Processed peas 0.5, carrots 1.8, potatoes 1.3 in. per month. Those for the cold-reduced cans were: Processed peas 0.2, carrots 1.8, potatoes 0.7 in. per month. Only cold-reduced plate was used in the tests with damsons and blackberries, where the whole of the two packs had formed hydrogen swells in less than three weeks and seven weeks respectively. Tinplate controls formed hydrogen swells at about one-tenth of this rate.

The conclusion that may be drawn from this small experiment is that all-blackplate cans compare favourably with cans having blackplate ends and tinplate bodies when used with vegetables, but very unfavourably when used with fruits. One reason for this may be found in the inhibitory action of tin ions on the corrosion of steel, which is much stronger at the pH of fruits than at that of vegetables.

EXTERNAL CORROSION OF CANS.

The conditions under which the cans were stored at 35° C. did not encourage external rusting of the cans, and very little was observed, though moisture condensed occasionally on the cans held at normal temperatures. In these cases some rusting was observed on the outer part of the seams of the blackplate cans where the lacquer had been loosened during seaming. The normal blackplate ends were decidedly worse in this respect than the phosphated ends.

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REFERENCES.

- (1) E. F. KOHMAN and N. H. SANBORN : *Industrial and Engineering Chemistry*, 1928 vol. 20, p. 76.
- (2) R. H. LUECK : *Canning Age*, 1927, vol. 8, p. 221.
- (3) E. C. MANTELL and E. S. LINCOLN : *Canning Age*, 1926, vol. 7, p. 84.
- (4) A. PIEGAI : *Industria Italiana delle Conserve Alimentari*, 1942, vol. 17, p. 17.
- (5) H. WEISE : *Korrosion und Metallschutz*, 1941, vol. 17, p. 363.
- (6) F. JAKOBSEN : *Tidsskrift for Hermetikindustri*, 1942, vol. 28, p. 251.
- (7) K. M. EDSÄTER : *Teknisk Tidskrift*, 1944, vol. 74, p. 61.
- (8) R. H. LUECK and K. W. BRIGHTON : *Industrial and Engineering Chemistry, Industrial Edition*, 1944, vol. 36, p. 532.
- (9) W. B. ADAM and D. DICKINSON : *Annual Report of the Fruit and Vegetable Preservation Research Station, Campden*, 1943, p. 16.
- (10) W. B. ADAM : *Annual Report of the Fruit and Vegetable Preservation Research Station, Campden*, 1943, p. 34.
- (11) D. DICKINSON : *Annual Report of the Fruit and Vegetable Preservation Research Station, Campden*, 1943, p. 40.

TESSELLATED STRESSES.—PART IV.*

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SYNOPSIS.

The criterion of making units of structural tessellation self-compensated is found to be the equality of the shear moduli of elasticity of the components.

Tessellated yield is analysed for lamellar and spherical structures, and iron and steel are discussed in this regard.

The possible influence of tessellated stresses and yield on the reshaping of structural components by annealing is investigated.

An argument based on the consideration of inter-atomic tessellated stresses is offered in support of the explanation of precipitation-hardening by the "blocking of potential slip planes."

Some problems connected with magnetization are discussed, and the question of internal friction is touched upon with reference to tessellated stresses.

INTRODUCTORY REMARKS.

FOR the sake of continuity with the author's previous publications on tessellated stresses, *viz.*, Parts I. to III.,¹ the numbers of equations, tables and diagrams given in this paper are continued from those in Part III. Occasional quotations of equations (1) to (36), Tables I. to XV. and Figs. 1 to 17 are to be referred to the previous Parts I. to III.

LIST OF SYMBOLS.

The notation of the present paper is mostly in accordance with that used in Parts I. to III. Certain modifications which appeared to be desirable and most of the new symbols are given in the following list :

$f_o, u_o, a_o, f_t, u_t, a_t$ replace respectively $f_1, u_1, a_1, f_2, u_2, a_2$ in equations (1), (1a), and (8), and Figs. 1 and 8 regarding lamellar tessellation.

$\epsilon_{y,o}, \epsilon_{y,t}$ = plastic strains of lamellar tessellation in the interior.

$f_{y,o}, f_{y,t}$ = yield stresses of the materials of the lamellæ.

$U_c = U + U_y$ = total strain energy.

U = elastic strain energy.

U_y = plastic strain energy.

α, β = suffixes for surface layer with lamellæ respectively at right angles and parallel to it.

$\alpha\alpha, \beta\beta$ = α and β respectively but referring specifically to surface layer generated by machining after the straining process.

f_y = yield stress of a spherical shell.

v_y = yielding inner zone of a spherical shell.

v_E = unyielding outer zone of a spherical shell.

r_E = outer limit of radial progress of yield in a spherical shell.

p_E = radial stress at the junction of the yielding and unyielding zones of a spherical shell.

ϵ_y = plastic tangential strain of a spherical shell at any radius r .

v, \bar{v} = volumes of spheres of radii r and ρ respectively.

$p_{1,2}$ = radial coupling stress between the components of a compound sphere, the components being inversely arranged.

U_s = strain energy of a compound sphere with the components in inverse arrangement.

α = suffix denoting auxiliary quantities for elastic affinity.

ξ_i = volume of an individual precipitated particle.

N = number of precipitated particles per unit volume.

* Received November 16, 1944.

ELASTIC AFFINITY.

It was mentioned in Part III. that equations (8), (9), and (10) account for the characteristic stress system only, since the units of tessellation are not self-compensated. The question arises as to what conditions should be fulfilled to make the units of tessellation of those equations self-compensated, *i.e.*, to cause the stresses q and p_s to vanish. In order to make the answer as simple as possible let us change the suffixes 1 and 2 into o and i respectively in equations (1), (8), and (19) for lamellar tessellation.

It is then found that the units become self-compensated with any possible shape of tessellation if :

$$G_i = \frac{m_i E_i}{2(m_i + 1)} = \frac{m_o E_o}{2(m_o + 1)} = G_o \quad \dots \quad (37)$$

Under such conditions equations (1) and (3) of Part I. become precise statistical solutions for the stresses in laminated slabs and compound cylinders respectively. Furthermore, equation (3) will become greatly simplified, and it is seen that :

$$p_j = \frac{\epsilon_i \epsilon_o (1 - w_i)(a_o - a_i)t}{2[\epsilon_i w_i + \epsilon_o (1 - w_i)]} = \frac{f_{a,i}}{2} = -\frac{1 - w_i}{2w_i} f_{a,o} \quad \dots \quad (38)$$

In general, in calculations with elastic affinity it is advisable to make use of expressions containing only $G = G_i = G_o$, $\epsilon_i = m_i E_i / (m_i - 1)$, and $\epsilon_o = m_o E_o / (m_o - 1)$ as elastic constants, *i.e.*, of the following types of substitutions :

$$\frac{m_i + 1}{m_i E_i} = \frac{m_o + 1}{m_o E_o} = \frac{1}{2G}; \quad \frac{m_i - 1}{m_i E_i} = \frac{1}{\epsilon_i}; \quad \frac{1}{E_o} = \frac{2G + \epsilon_o}{4\epsilon_o G}; \quad \frac{1}{m_i E_i} = \frac{\epsilon_i - 2G}{4\epsilon_i G};$$

$$\frac{m_i - 2}{m_i E_i} = \frac{6G - \epsilon_i}{4\epsilon_i G} \quad \dots \quad (39)$$

If tessellated stresses are caused by an internal strain potential, such as $\lambda = (a_o - a_i)t$, it is found that the apparent coefficient of thermal expansion α , the yield potential $f_{red,o}$ and the strain energy U are independent of the shape of tessellation, their values being :

$$\alpha = \frac{\epsilon_i X_i a_i + \epsilon_o (1 - X_i) a_o}{\epsilon_i X_i + \epsilon_o (1 - X_i)} \quad \dots \quad (40a)$$

$$f_{red,o} = \frac{\epsilon_i \epsilon_o \lambda}{\epsilon_i X_i + \epsilon_o (1 - X_i)} \quad \dots \quad (40b)$$

$$U = \frac{\epsilon_i \epsilon_o X_i (1 - X_i)}{\epsilon_i X_i + \epsilon_o (1 - X_i)} \lambda^2 \quad \dots \quad (40c)$$

where X_i and $(1 - X_i)$ denote respectively the volume fractions of the i and o components whatever their shape. The strain energy is a maximum at $X_i = (\sqrt{\epsilon_i \epsilon_o} - \epsilon_i) / (\epsilon_o - \epsilon_i) \pm \frac{1}{2}$, if $\epsilon_i \neq \epsilon_o$.

As quoted by Nabarro ² (*loc. cit.*, p. 528), M. M. Crum found that the strain energy developed owing to the relative change in volume of a small inclusion or precipitate in the centre of an infinite matrix is independent of the shape of the inclusion if $G_i = G_o$. It should be added, as an acknowledgment of their pioneering merits, that Mott and Nabarro ³ found from simplified considerations that the strain energy due to structural tessellation of small precipitated particles in a matrix is proportional to the volume fraction of the precipitate. This finding is correct in general for small values of X_i .

It is now seen that the case of elastic identity of the structural components, *viz.*, $m_i = m_o$ and $E_i = E_o$, which leads to equations (1a), (2a),

(3a), (4), and (21), is a particular branch of the general criterion of elastic affinity.

When there is elastic affinity, the units of tessellation prove to be self-compensated also when subjected to an external direct stress f . On putting $G_1 = G_2$ in equation (14), it is noticed for lamellar tessellation that :

$$q_{IIII} = 0; \quad q_I = f; \quad u_1 f_{1,I} + u_2 f_{2,I} = f; \quad u_1 f_{1,IIII} + u_2 f_{2,IIII} = 0; \\ u_1 f_{1,II-III} + u_2 f_{2,II-III} = 0$$

and the elastic constants of the compound body are :

$$G = \frac{mE}{2(m+1)} = G_1 = G_2 \quad \text{and} \quad \epsilon = \frac{mE}{m-1} = u_1 \epsilon_1 + u_2 \epsilon_2 \quad . \quad . \quad (41)$$

The principal load factors per unit area are the following :

$$\left. \begin{aligned} [f_{1,I}]_{+1} &= \frac{1}{2\epsilon} [2u_1 \epsilon_1 + u_2 (\epsilon_1 + \epsilon_2)]; \quad [f_{2,I}]_{+1} = \frac{1}{2\epsilon} [2u_2 \epsilon_2 + u_1 (\epsilon_1 + \epsilon_2)] \\ [f_{1,II-III}]_{+1} &= [f_{1,IIII}]_{+1} = \frac{1}{2\epsilon} u_2 (\epsilon_1 - \epsilon_2) \\ [f_{2,II-III}]_{+1} &= [f_{2,IIII}]_{+1} = -\frac{1}{2\epsilon} u_1 (\epsilon_1 - \epsilon_2) \end{aligned} \right\} \quad (42)$$

For spherical tessellation equation (17) is suggested if external direct stress is to be considered. This representation with the help of parallel-oriented capped cylinders is only a very auxiliary method, since the units with rotational symmetry are not arranged at random with regard to the direction of the axis symmetry. Nevertheless, on putting $G_1 = G_2$ in equation (17), it is found that equation (41) is obtained again. Apparently the elasticity of the compound aggregate is also independent of the shape of tessellation when there is elastic affinity, and the units are invariably self-compensated. With pseudo-spherical tessellation the load factors per unit area are as follows :

$$\left. \begin{aligned} [p_j]_{+1} &= \frac{1}{4\epsilon} (\epsilon_i - \epsilon_o)(1 + b^2 - 2b^3); \quad [p_s]_{+1} = \frac{1}{2\epsilon} (\epsilon_i - \epsilon_o)(b^2 - b^3); \\ [p]_{+1} &= -\frac{1}{2\epsilon} (\epsilon_i - \epsilon_o)b^3 \\ [f_{a,i}]_{+1} &= \frac{1}{2\epsilon} [(\epsilon_i + \epsilon_o) - (\epsilon_i - \epsilon_o)(b^2 - 2b^3)] \\ [f_{a,o}]_{+1} &= \frac{1}{2\epsilon} [2\epsilon_o - (\epsilon_i - \epsilon_o)(b^2 - 2b^3)] \end{aligned} \right\} \quad (43)$$

With an external direct stress f , no tessellated stresses develop, of course, in the case of elastic identity.

TESSELLATED YIELD.

When calculating on the basis of perfect elasticity, structural tessellated stresses of such a magnitude were sometimes obtained that the question arose whether or not tessellated yield would occur and redistribute the stresses. For instance, regarding the cooling stresses of cast iron, experiments indicated the yield of the graphite lamellæ. Their yield stress is of course negligibly small both in the absolute sense and in comparison with the yield potential found for them on the basis of elasticity. The previous study of the tessellated stresses involved in the cooling of black-heart malleable iron and spheroidized steel, and of those found for retained austenite, suggests that the investigation should be extended to the spherical system of tessellation. The following discussion refers exclu-

sively to structural tessellation, the components of which are assumed each to be random aggregates of crystals.

Denoting the components of the lamellar structure again with o and i , instead of the previous suffixes 1 and 2, the following equations account for the characteristic component system of tessellated stresses and yield (see Fig. 8):

$$\left. \begin{aligned} at &= a_o t + s_{y,o} + \frac{m_o - 1}{m_o E_o} f_o - \frac{q}{m_o E_o} = a_i t + s_{y,i} + \frac{m_i - 1}{m_i E_i} f_i - \frac{q}{m_i E_i} \\ 3at &= u_i \left(3a_i t + 2 \frac{m_i - 1}{m_i E_i} f_i - 2 \frac{q}{m_i E_i} + \frac{q}{E_i} - 2 \frac{f_i}{m_i E_i} \right) \\ &\quad + (1 - u_i) \left(3a_o t + 2 \frac{m_o - 1}{m_o E_o} f_o - 2 \frac{q}{m_o E_o} + \frac{q}{E_o} - 2 \frac{f_o}{m_o E_o} \right) \\ 2(1 - u_i)f_o + 2u_i f_i + q &= 0; \quad f_o = q + f_{y,o}; \quad f_i = q + f_{y,i} \end{aligned} \right\} \quad (44)$$

where $s_{y,o}$ and $s_{y,i}$ are the plastic strains of the o and i lamellæ respectively, being circularly uniform in the plane of the lamellæ, and $f_{y,o}$ and $f_{y,i}$ are the respective yield stresses of their materials. It is assumed that strain-hardening is negligible and that plastic strains do not affect the density. If one component, say, o , does not yield, $s_{y,o} = 0$ and $f_o \neq q + f_{y,o}$. If neither component yields equation (44) becomes identical with equation (8). The sign of $f_{y,i}$ should be made the same as that of $\lambda = (a_o - a_i)t$, and $f_{y,o}$ should have the opposite sign.

The strain energy is:

$$U_c = U + U_y = U + 2u_i s_{y,i} f_{y,i} + 2(1 - u_i) s_{y,o} f_{y,o} \quad (45)$$

where U denotes the elastic strain energy calculated with equation (19), and U_y is generated by tessellated yield.

Regarding the surface layer, its stresses and actual tessellated yield depend on whether it has been machined since the straining process.

From certain aspects, it is of interest to consider tessellated yield of the lamellar structure with self-compensated units. The results will then be exact in the statistical sense. The units become self-compensated if $q = 0$, necessitating, in accordance with equation (44), that:

$$\left. \begin{aligned} \frac{f_o}{f_i} &= \frac{f_{y,o}}{f_{y,i}} = - \frac{u_i}{1 - u_i} \\ \text{and} \quad at &= [u_i a_i + (1 - u_i) a_o] t + \frac{2}{3} (1 - u_i) \left(\frac{m_o - 2}{m_o E_o} - \frac{m_i - 2}{m_i E_i} \right) \end{aligned} \right\} \quad (46)$$

Lamellar graphite has been investigated first for $f_{y,g} = 0$ and $s_{y,g} = 0$, i.e., on the assumption that graphite yields without resistance and the metallic matrix does not yield at all. For the sake of comparison with previous results, a ferrite matrix and a temperature drop of 680° C. have been considered again. The results, viz., the figures for y 2 and y 2.18, are shown in Table XVI. together with the stresses E 2 and E 2.18 calculated for the case of no yield and given previously in Table IV. The possibility that lamellar graphite would be unyielding seems so remote that the values of Table IV. for f_g and $f_{red,g}$ have not been quoted in Table XVI. If graphite yields without resistance, it becomes subjected to hydrostatic stresses, i.e., $f_g = q$, and of course to no shear stress at all, i.e., $f_{red,g} = 0$. These essential features are not indicated in Table XVI. The influence of the yield of graphite on the stress redistribution in the metallic matrix cannot be more favourable than obtained for $f_{y,g} = 0$. This influence appears, however, to be approximately zero on the "average," i.e., the yield of graphite would not cause any stress relief in the metallic matrix at all, as shown in rows 2 and 3 of Table XVI. This practically holds for surface intersections too, see rows 7 and 8. With the assumptions

TABLE XVI.—Tessellated Yield with Lamellar Graphite ($\epsilon_{7g} = 0$) in Unyielding Ferrite Matrix due to a Temperature Drop of 680°C .

Row.	Stresses Developing—	Stresses, lb./sq. in. Strain Energy, lb./cu. in.	m_g	Graphite, wt.-%.							
				0.01.	0.05.	0.1.	0.5.	1.	2.	3.	4.
1		g	E_2 y_2 y_2 y_2 E_2 E_2 E_2 E_2	-123 -127 -127 -127 -110 +68 +64 +61	-613 -635 -631 -647 -547 +341 +319 +317 +305	-1,222 -1,266 -1,266 -1,262 -1,086 +683 +639 +601 +609	-5,967 -6,180 -5,862 -18,854 -5,121 +3,466 +3,255 +3,086 +2,983	-11,570 -11,993 -10,853 -18,854 -9,550 +7,040 +6,632 +6,001 +5,825	-21,755 -22,683 -18,854 -16,790 -14,470 +13,708 +11,444 +11,180	-30,735 -31,891 -29,640 -22,405 +23,175 +25,762 +21,295 +20,980	-38,560 -40,033 -29,640 -26,845 +30,070 +30,762 +21,295 +20,980
2		f_f	E_2 y_2 y_2 y_2 E_2 E_2 E_2 E_2	+68 +64 +64 +61	+341 +319 +317 +305	+683 +639 +601 +609	+3,466 +3,255 +3,086 +2,983	+7,040 +6,632 +6,001 +5,825	+14,470 +13,708 +11,444 +11,180	+23,175 +25,762 +21,295 +20,980	+30,070 +30,762 +21,295 +20,980
3		$f_{red}, f = f_f - g$	E_2 y_2 y_2 y_2 E_2 E_2 E_2 E_2	191 191 191 171	954 954 948 862	1,905 1,905 1,885 1,695	9,433 9,433 8,948 8,104	18,610 18,625 16,854 15,375	36,245 36,291 30,298 27,970	53,910 53,907 41,433 38,610	68,630 68,795 50,935 47,825
4	In interior of body.	$10^6 a$	E_2 y_2 y_2 y_2 E_2 E_2 E_2 E_2	14,976 14,976 14,976 14,976 14,976 14,976 14,976 14,976	14,959 14,960 14,960 14,960 14,960 14,960 14,962 14,962	14,959 14,940 14,940 14,940 14,940 14,940 14,943 14,943	14,773 14,778 14,780 14,780 14,788 14,803 14,803 14,803	14,568 14,578 14,584 14,614 14,640 14,640 14,640 14,640	14,164 14,178 14,207 14,310 14,349 14,349 14,349 14,349	13,768 13,786 13,847 13,947 14,047 14,088 14,088 14,088	13,380 13,404 13,504 13,604 13,813 13,854 13,854 13,854
5		U	E_2 y_2 y_2 y_2 E_2 E_2 E_2 E_2	0.0525 0.0005 0.0005 0.0005 0.0485 0.0079 0.0079 0.0079	0.271 0.013 0.013 0.013 0.250 0.0079 0.0079 0.0079	0.551 0.052 0.052 0.052 0.517 0.0079 0.0079 0.0079	3.54 1.26 1.26 1.26 3.14 0.0078 0.0074 0.0074	9.56 4.84 4.84 4.84 8.01 0.0076 0.0069 0.0069	20.4 17.8 17.8 17.8 20.5 0.0074 0.0061 0.0061	48.5 36.8 36.8 36.8 35.6 0.0071 0.0055 0.0055	74.4 60.3 60.3 60.3 51.6 0.0068 0.0051 0.0051
6		$s_{y, g}$	y_2 y_2 y_2 y_2 E_2 E_2 E_2 E_2	+92 +83 +83 +93	+475 +414 +411 +460	+946 828 818 915	+4,585 +4,131 +3,919 +4,342	+8,925 8,240 7,457 8,165	+17,245 +16,371 +13,667 +14,850	+25,265 +24,348 +19,032 +20,685	+33,055 +32,143 +23,798 +25,835
7	In surface intersections—	f_{red}, f, a	E_2 y_2 y_2 y_2 E_2 E_2 E_2 E_2	+124 +118 +118 +103	+602 +591 +588 +538	+1,203 +1,182 +1,169 +1,079	+6,047 +5,901 +5,598 +5,164	+12,000 +11,771 +10,652 +9,920	+23,790 +23,387 +19,624 +18,399	+35,335 +34,784 +27,189 +26,010	+46,620 +45,919 +38,998 +32,810
8	Parallel to lamellae.	f_f, β	E_2 y_2 y_2 y_2 E_2 E_2 E_2 E_2	+124 +118 +118 +103	+602 +591 +588 +538	+1,203 +1,182 +1,169 +1,079	+6,047 +5,901 +5,598 +5,164	+12,000 +11,771 +10,652 +9,920	+23,790 +23,387 +19,624 +18,399	+35,335 +34,784 +27,189 +26,010	+46,620 +45,919 +38,998 +32,810

mentioned, viz., $f_{y,g} = 0$ and $s_{y,f} = 0$, there is no difference between the stresses which develop in original surface layers and in those which have been made surface layers by machining after the straining process. The plastic strain of graphite will be greatly modified at the surface, since $f_g = q = 0$ is to be established there. The stresses shown in rows 7 and 8 are then obtained from :

$$at = a_f t + \frac{f_{f,a}}{E_f} \quad \text{and} \quad at = a_f t + \frac{m_f - 1}{m_f E_f} f_{f,\beta} \quad . \quad . \quad . \quad (47)$$

If the ferritic matrix is supposed to yield in addition, all stresses are reduced. Table XVII. has been calculated, for 2% and 3% of carbon only, with $f_{y,g} = 0$ and $f_{y,f} = 20,000$ lb. per sq. in. The latter value is improbably low; it should be considered as an indication of the lower limit. Regarding the plastic strain of graphite, viz., row 6 of Table XVI. and row 7 of Table XVII., it is noteworthy that $s_{y,g} < 0$ in both cases, i.e., the graphite lamellæ are subjected to compacting by cooling stresses.

TABLE XVII.—*Tessellated Yield with Lamellar Graphite and its Ferrite Matrix due to a Temperature Drop of 680° C., for $f_{y,g} = 0$ and $f_{y,f} = f_{\text{red},f} = 20,000$ lb. per sq. in.*

Row.	Stresses, lb./sq. in. Strain Energy, in. lb./cu. in.	m_g	Graphite, wt.-%.	
			2.	3.
1	$q = f_g$	$\left\{ \begin{smallmatrix} 2 \\ 2.18 \end{smallmatrix} \right\}$	-12,446	-12,033
2	f_f	$\left\{ \begin{smallmatrix} 2 \\ 2.18 \end{smallmatrix} \right\}$	+ 7,554	+ 7,967
3	$10^6 a$	$\left\{ \begin{smallmatrix} 2 \\ 2.18 \end{smallmatrix} \right\}$	14.191 14.275	13.824 13.944
4	U	$\left\{ \begin{smallmatrix} 2 \\ 2.18 \end{smallmatrix} \right\}$	5.4 6.5	5.2 6.7
5	U_y	$\left\{ \begin{smallmatrix} 2 \\ 2.18 \end{smallmatrix} \right\}$	8.8 6.7	17.3 14.4
6	U_c	$\left\{ \begin{smallmatrix} 2 \\ 2.18 \end{smallmatrix} \right\}$	14.2 13.2	22.5 21.1
7	$s_{y,g}$	$\left\{ \begin{smallmatrix} 2 \\ 2.18 \end{smallmatrix} \right\}$	-0.0074 -0.0066	-0.0071 -0.0064
8	$s_{y,f} = s_{y,f,aa}$	$\left\{ \begin{smallmatrix} 2 \\ 2.18 \end{smallmatrix} \right\}$	+0.0002 +0.0002	+0.0005 +0.0004
9	$f_{f,aa}$	$\left\{ \begin{smallmatrix} 2 \\ 2.18 \end{smallmatrix} \right\}$	+ 9,022	+ 9,187
10	$f_{f,\beta\beta}$	$\left\{ \begin{smallmatrix} 2 \\ 2.18 \end{smallmatrix} \right\}$	+12,888	+13,124
11	$f_{f,a}$	$\left\{ \begin{smallmatrix} 2 \\ 2.18 \end{smallmatrix} \right\}$	+16,601 +14,382	+20,000
12	$s_{y,f,a}$	$\left\{ \begin{smallmatrix} 2 \\ 2.18 \end{smallmatrix} \right\}$	... ...	+0.00012 +0.00004
13	$f_{f,\beta}$	$\left\{ \begin{smallmatrix} 2 \\ 2.18 \end{smallmatrix} \right\}$	+20,000	+20,000
14	$s_{y,f,\beta}$	$\left\{ \begin{smallmatrix} 2 \\ 2.18 \end{smallmatrix} \right\}$	+0.00007 +0.00001	+0.00032 +0.00024

Rows 9 and 10 account for the stresses of ferrite in surfaces generated by machining after straining. Since this metal has been plastically stretched by $s_{y,f}$ in accordance with row 8, its stresses are obtained from :

$$at = a_f t + s_{y,f} + \frac{f_{f,aa}}{E_f} \quad \text{and} \quad at = a_f t + s_{y,f} + \frac{m_f - 1}{m_f E_f} f_{f,\beta} \quad . \quad (48a)$$

The surface layer, however, which has been strained as such and not

machined afterwards, will only yield with α or β arrangements of the lamellæ if respectively :

$$\frac{1}{f_{y,f}} E (a - a_f) t > 1 \quad \text{or} \quad \frac{m_f E_f}{f_{y,f} (m_f - 1)} (a - a_f) t > 1 \quad . \quad . \quad . \quad (48b)$$

Its stresses and individual tessellated yield are therefore obtained from either of the following pairs of equations, for α and β interfaces respectively :

$$\left. \begin{aligned} at &= a_f t + \frac{f_f a}{E_f} \quad \text{or} \quad at = a_f t + s_{y,f,a} + \frac{f_{y,f}}{E_f} \\ at &= a_f t + \frac{m_f - 1}{m_f E_f} f_{f,\beta} \quad \text{or} \quad at = a_f t + s_{y,f,\beta} + \frac{m_f - 1}{m_f E_f} f_{y,f} \end{aligned} \right\} \quad . \quad (48c)$$

It is noteworthy that there is a definite tendency for greater tessellated stresses and less tessellated yield to occur in an original surface layer than in one machined after straining. However, this mathematical result might be modified by the yield resistance of the metallic surface layer being considerably less than that in the interior. This uncertainty and the lack of experimental evidence which would assist towards its removal are unpleasant, since the question is of some interest to metallurgists. If an "original" surface layer is in the as-cast condition, phenomena not connected with tessellated stresses may overshadow the possible effects of the above observations. However, numerous iron castings are pre-machined, subsequently stress-relieved at fairly high temperatures, and in the finishing process machined on some surfaces only. The final machining, of course, may have the disadvantage of causing considerable residual strains and stresses due to a more or less rough finish. It should also be mentioned that, regardless of whether cast iron is concerned or not, tessellated yield may involve consequential precipitation processes with their usual after-effects, which are then superimposed on those of the stresses analysed above and in the following.

Regarding spherical tessellation, the core substance is subjected to a hydrostatic stress p_j , and it should be remembered that neither shear stress nor yield can develop in it. If the matrix yields, the process will start at the junction r_j of the structural components and extend from there outwards to a certain intermediate spherical surface of radius r_E . In the outermost zone between r_E and r_s , the matrix will be purely elastically strained. (See Fig. 18.) Let the volumes of the whole unit of tessellation, of its core and outer shell, and of the yielding and unyielding zones of the latter be denoted respectively by :

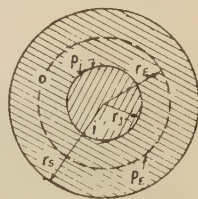


FIG. 18. — Compound Sphere with Partially Yielding Shell.

$$1 = \frac{4\pi}{3} r_s^3; v_i = \frac{4\pi}{3} r_j^3; v_o = 1 - v_i = \frac{4\pi}{3} (r_s^3 - r_j^3); v_y = \frac{4\pi}{3} (r_E^3 - r_j^3); v_E = \frac{4\pi}{3} (r_s^3 - r_E^3).$$

It is convenient to introduce special notations for the volumes enclosed by any spherical shell of radius r or ρ , viz., $v = \frac{4\pi}{3} r^3$ and $\bar{v} = \frac{4\pi}{3} \rho^3$, and for their elementary increments, viz., $dv = 4\pi r^2 dr$ and $d\bar{v} = 4\pi \rho^2 d\rho$ respectively.

The volume v_E does not yield and its stresses at any radial distance $r_E < r < r_s$ from the centre of the compound sphere are therefore :

$$f_r = - \frac{1 - v_E}{v_E} \cdot p_E + \frac{1 - v_E}{v_E} \cdot \frac{p_E}{v} \quad \text{and} \quad f_t = - \frac{1 - v_E}{v_E} \cdot p_E - \frac{1 - v_E}{v_E} \cdot \frac{p_E}{2v} \quad (49a)$$

in terms of the radial "junction" stress p_E at r_E . The maximum yield

potential develops at $r = r_E$, and the value of p_E is obtained from the requirement that $f_{red, E} = [f_i - f_r]_{r=r_E} = f_y$, where f_y denotes the yield stress of the matrix which is again considered to be unaffected by strain-hardening. The sign of f_y is to be taken opposite to that of $\lambda = (a_o - a_i)t$, as has been mentioned above. Then:

$$p_E = -\frac{2}{3}v_E f_y \quad . \quad . \quad . \quad . \quad . \quad . \quad (49b)$$

The interdependence of the tangential and radial stresses at any radius $r, r < r_E$ in the yielding zone of the matrix is expressed by the differential equation:

$$r f_i = \frac{1}{2} \frac{d}{dr} (r^2 f_r) \quad . \quad . \quad . \quad . \quad . \quad . \quad (50a)$$

On considering that in the yielding zone $f_i = f_r + f_y$ at any radius r , and that $[f_r]_{r=r_E} = p_E$, it is found that:

$$f_r = -\frac{2}{3}v_E f_y + \frac{2}{3}f_y \log_e \frac{v}{1-v_E} \quad \text{and} \quad f_i = f_y - \frac{2}{3}v_E f_y + \frac{2}{3}f_y \log_e \frac{v}{1-v_E} \quad (50b)$$

furthermore:

$$p_j = -\frac{2}{3}v_E f_y + \frac{2}{3}f_y \log_e \frac{v_i}{1-v_E} \quad . \quad . \quad . \quad . \quad . \quad . \quad (50c)$$

The value of v_E is obtained from the consideration that the change in volume of $(v_i + v_y)$ must be equal to that of the (internal spherical) cavity of the outermost zone of the matrix v_E , i.e.:

$$\begin{aligned} v_i \left(3a_i t + 3 \frac{m_i - 2}{m_i E_i} p_j \right) + v_y (3a_o t) + \int_{v_i}^{1-v_E} \frac{m_o - 2}{m_o E_o} (2f_i + f_r) dv \\ = 4\pi r_E^3 \left[r_E \left(a_o t + \frac{m_o - 1}{m_o E_o} f_{i, E} - \frac{p_E}{m_o E_o} \right) \right] \end{aligned}$$

where f_i and f_r refer to equation (50b), and $f_{i, E}$ to equation (49a). It is then found that:

$$\begin{aligned} v_E \left[\frac{3}{2} \cdot \frac{m_o - 1}{m_o E_o} + \left(\frac{m_o - 2}{m_o E_o} - \frac{m_i - 2}{m_i E_i} \right) v_i \right] - \left(\frac{m_o - 2}{m_o E_o} - \frac{m_i - 2}{m_i E_i} \right) \log_e \frac{v_i}{1-v_E} \\ = \frac{3}{2} \frac{(a_o - a_i)t}{f_y} + \frac{3}{2} \cdot \frac{m_o - 1}{m_o E_o} \quad (51a) \end{aligned}$$

and for:

$$\frac{m_o - 2}{m_o E_o} = \frac{m_i - 2}{m_i E_i}; v_E = 1 + \frac{m_o E_o}{m_o - 1} \cdot \frac{(a_o - a_i)t}{f_y} v_i \quad . \quad . \quad (51b)$$

The coefficient of thermal expansion α of the unit as a whole is $\alpha t = a_o t + \frac{m_o - 1}{m_o E_o} f_{i, E}$, which with equations (49a) and (49b) results in:

$$\alpha t = a_o t + \frac{m_o - 1}{m_o E_o} f_y (1 - v_E) \quad . \quad . \quad . \quad . \quad . \quad . \quad (51c)$$

The tangential plastic strain s_y at any radius r is obtained from:

$$\begin{aligned} v_i \left(3a_i t + 3 \frac{m_i - 2}{m_i E_i} p_j \right) + (v - v_i)(3a_o t) + \int_{v_i}^v \frac{m_o - 2}{m_o E_o} (2\bar{f}_i + \bar{f}_r) d\bar{v} \\ = 4\pi r^3 \left[r \left(a_o t + s_y + \frac{m_o - 1}{m_o E_o} f_i - \frac{f_r}{m_o E_o} \right) \right] \end{aligned}$$

where \bar{f}_i and \bar{f}_r are given by equation (50b), the same symbols with bars being likewise given by equation 50(b) but modified by replacing v by \bar{v} .

Hence :

$$s_y = -\frac{v_i}{v}(\alpha_o - \alpha_i)t - \frac{m_o - 1}{m_o E_o} f_y + \frac{2}{3} \frac{v_i v_E}{v} \left(\frac{m_o - 2}{m_o E_o} - \frac{m_i - 2}{m_i E_i} \right) f_y - \frac{2}{3} \frac{v_i}{v} \left(\frac{m_o - 2}{m_o E_o} - \frac{m_i - 2}{m_i E_i} \right) f_y \log_e \frac{v_i}{1 - v_E} \quad (51d)$$

The strain energy of the whole unit of tessellation is :

$$U_s = \frac{3}{2} \cdot \frac{m_i - 2}{m_i E_i} v_i p_i^2 + \int_{v_i}^{1 - v_E} \left(\frac{m_o - 1}{m_o E_o} f_i^2 + \frac{f_r^2}{2 E_o} - 2 \frac{f_i f_r}{m_o E_o} \right) dv + \left(\frac{9}{4} \cdot \frac{m_o - 1}{m_o E_o} \cdot \frac{1 - v_E}{v_E} + \frac{3}{4} \cdot \frac{m_o + 1}{m_o E_o} \right) (1 - v_E) p_E^2 + \int_{v_i}^{1 - v_E} (2 f_y s_y) dv \quad (52a)$$

where f_i and f_r are given by equation (50b) and s_y by equation (51d), and the last term accounts for the energy U_y due to plastic flow. The integrals have the following values :

$$\int_{v_i}^{1 - v_E} \left(\frac{m_o - 1}{m_o E_o} f_i^2 + \frac{f_r^2}{2 E_o} - 2 \frac{f_i f_r}{m_o E_o} \right) dv = v_y \left(\frac{m_o - 1}{m_o E_o} + \frac{2}{3} v_E^2 \frac{m_o - 2}{m_o E_o} \right) f_y^2 + \frac{4}{3} v_i v_E \frac{m_o - 2}{m_o E_o} f_y^2 \log_e \frac{v_i}{1 - v_E} - \frac{2}{3} v_i \frac{m_o - 2}{m_o E_o} \left(\log_e \frac{v_i}{1 - v_E} \right)^2 f_y^2 \quad (52b)$$

$$U_y = \int_{v_i}^{1 - v_E} (2 f_y s_y) dv = 2 v_i f_y (\alpha_o - \alpha_i) t \log_e \frac{v_i}{1 - v_E} - 2 v_y \frac{m_o - 1}{m_o E_o} f_y^2 - \frac{4}{3} v_i v_E \left(\frac{m_o - 2}{m_o E_o} - \frac{m_i - 2}{m_i E_i} \right) f_y^2 \log_e \frac{v_i}{1 - v_E} + \frac{4}{3} v_i \left(\frac{m_o - 2}{m_o E_o} - \frac{m_i - 2}{m_i E_i} \right) f_y^2 \left(\log_e \frac{v_i}{1 - v_E} \right)^2 \quad (52c)$$

The above analysis refers to the general case of $0 < v_y < (1 - v_i)$ and simultaneously $(1 - v_i) > v_E > 0$. Yield starts if $f_{red, of}$ found from equation (2) reaches the magnitude of the yield resistance f_y of the matrix. If the whole matrix begins to yield, $v_E = 0$, and the corresponding critical value $f_{y, crit.}$ of the yield stress is readily obtained from either equation (51a) or (51b). If yield progresses further, equations (51a) and (51b) become unnecessary. It is found by special investigation that most of the results obtained for $v_E > 0$, viz., equations (49a) to (50c) and (51d) to (52c) are invariably correct also for $v_y = (1 - v_i)$, if $v_E = 0$ is substituted in them.

If the matrix yields over its whole mass, the thermal expansion of the unit as a whole is affected by the tangential plastic strain $s_{y, s}$ at its outer surface r_s . The latter is obtained from equation (51d) by putting $v = 1$ and $v_E = 0$. Finally it is seen that :

$$at = a_o t + s_{y, s} + \frac{m_o - 1}{m_o E_o} f_y = v_i a_i t + (1 - v_i) a_o t - \frac{2}{3} v_i \left(\frac{m_o - 2}{m_o E_o} - \frac{m_i - 2}{m_i E_i} \right) f_y \log_e v_i \quad (53)$$

Stresses and strains have been calculated for black-heart malleable iron with 2% and 3% of carbon (by weight) for tentative yield stresses (f_y) of 20,000, 50,000, 100,000 and 300,000 lb. per sq. in., the last being applicable with $m_y = 2$ only. Figures obtained for any unyielding matrix, given in Table V., have also been included in Table XVIII.

Spheroidized steel has been investigated for five carbon concentrations, viz., 0.05, 0.4, 0.83, 1.2, and 1.5%, and for $f_y = 20,000$ and 50,000 lb. per sq. in. The results, together with figures calculated for an unyielding matrix, i.e., for $f_y \geq 82183$, are listed in Table XIX. Once more, a temperature drop of 680° C. has been considered.

TABLE XVIII.—*Tessellated Yield of Ferrite Matrix Enclosing Spherical Graphite due to a Temperature Drop of 680° C.*

Row.	Stresses, lb./sq. in. Strain Energy, in. lb./cu. in.	Graphite, wt.-%.	m_g									
			2.	2-18.	2.	2-18.	2.	2-18.	2-18.	2.	2-18.	2.
1	$f_y, f = f_{red}, f^*$	3	20,000		50,000		100,000		$\geq 135,960$ $\geq 138,715$	300-000	$\geq 525,060$ $\geq 515,610$	2.
2	v_y	3	0-933 0-902	0-774 0-902	0-448 0-648	0-169 0-260	0-213 0-308	0-027 0-042	...	0-044 0-062	...	...
3	v_E	2	...	0-160	0-485 0-255	0-765 0-642	0-720 0-595	0-907 0-860	0-933 0-902	0-890 0-840	0-933 0-902	...
4	p_E	2	...	— 2,131	— 16,176 — 8,495	— 25,490 — 21,401	— 48,003 — 39,661	— 60,451 — 57,331	$= p_j$ $= p_j$	— 177,900 — 168,094	$= p_j$ $= p_j$	...
5	p_j	2	— 36,125 — 31,032	— 35,934 — 31,032	— 84,351 — 76,269	— 67,571 — 54,818	— 143,752 — 134,576	— 82,896 — 81,431	— 84,605 — 83,450	— 279,222 — 266,467	— 326,730 — 310,210	...
6	U	2	7-0	15-7	31-2	45-8	69	64-3	66-7	195	258	...
	U_y	2	43-0	25-3	56-6	15-0	88	2-2	...	50	...	...
	U_c	2	50-0	41-0	87-8	60-8	157	66-5	66-7	245	258	...
7	U	3	6-5	16-3	38	53-1	93	92-2	96-4	273	358	...
	U_y	3	58-6	39-1	101	16-9	125	3-8	...	69	...	...
	U_c	3	65-1	55-4	139	70-0	218	96-0	96-4	342	358	...
8	$f_{t,os}$	2	+ 20,000 + 20,000	+ 16,804 + 20,000	+ 25,757 + 37,258	+ 11,765 + 17,899	+ 27,996 + 40,508	+ 9,223 + 14,003	+ 9,050 + 13,550	+ 33,150 + 47,869	+ 34,960 + 50,300	...
9	10^{62}	2	14-160 13-788	14-403 14-096	14-097 13-702	14-576 14-366	14-019 13-590	14-660 14-500	14-669 14-516	13-842 13-338	13-781 13-254	...
10	$s_{y,f}$	2	+ 0-0079 + 0-0078	+ 0-0054 + 0-0057	+ 0-0079 + 0-0078	+ 0-0030 + 0-0037	+ 0-0075 + 0-0074	+ 0-0009 + 0-0010	...	+ 0-0046 + 0-0045	...	...
11	$s_{y,s}$	2	+ 0-00009 + 0-00034	...	...	...	...	...	...	...	...	...

* For 2% and 3% of graphite respectively the values of v_y are 0-067 and 0-098, whilst those of f_y crit. are 24,190 and 26,131 with $m_g = 2$ and 17,494 and 24,232 with $m_g = 2-18$.

TABLE XIX.—*Tessellated Yield of Ferrite Matrix Enclosing Spheroidized Cementite due to a Temperature Drop of 680° C.*

Row.	Stresses, lb./sq. in. Strain Energy, in. lb./cu. in.	f_y .	Carbon, wt.-%.*				
			0.05.	0.4.	0.83.	1.2.	1.5.
1	v_i	...	0.008	0.061	0.127	0.184	0.229
2	v_y	20,000	0.024	0.191	0.395	0.571	0.713
		50,000	0.005	0.040	0.082	0.118	0.148
3	v_E	20,000	0.968	0.748	0.477	0.246	0.058
		50,000	0.987	0.899	0.791	0.698	0.623
		$\geq 82,183$	0.992	0.939	0.873	0.816	0.771
4	p_E	20,000	-12,913	-9,970	-6,365	-3,273	-772
		50,000	-32,913	-29,970	-26,365	-23,273	-20,772
5	p_f	20,000	-31,756	-28,813	-25,208	-22,116	-19,615
		50,000	-49,477	-46,534	-42,929	-39,837	-37,336
		$\geq 82,183$	-54,368	-51,425	-47,820	-44,728	-42,227
6	U	...	0.508	3.44	6.0	7.1	7.2
	U_y	20,000	0.387	3.09	6.4	9.2	11.5
	U_c	...	0.895	6.53	12.4	16.3	18.7
7	U	...	1.02	7.60	14.4	19.4	22.3
	U_y	50,000	0.16	1.24	2.6	3.7	4.6
	U_c	...	1.18	8.84	17.0	23.1	26.9
8	$U = U_c$	$\geq 82,183$	1.20	9.08	17.5	23.6	27.8
9	$f_t, \text{cs} (= f_y, \text{crit.})$	...	+631	+5,045	+10,452	+15,091	+18,842
10	$10^6 \alpha$	...	14.958	14.807	14.621	14.462	14.333

* With any percentage of carbon the values of $s_{y,f}$ are +0.0015 and +0.0008 for $f_y = 20,000$ and 50,000 respectively.

While the analysis of tessellated yield eliminates certain hypothetical features of some previous calculations, there is still work to be done on the problem if the qualitative knowledge now gained is to be advanced quantitatively. Regarding graphite in ferrous matrices the uncertainty concerning Poisson's ratio should first be removed, as has been suggested before. Next the super-elasticity of the metallic matrices of both cast iron and black-heart malleable iron is to be queried, together with their simple yield resistance, which is the controlling factor for "original" surfaces. Another question is whether graphite is truly compact in cast iron and black-heart malleable iron. Porosity due to gas rejection might affect the above analysis, and it would be of great assistance if, for instance, the volume change of cast iron were to be investigated over long periods at room temperature, and also the gases which possibly escape. While there is no doubt of the tessellated yield of lamellar graphite, much uncertainty is left regarding that of its metallic matrix. The above analysis was based among other things on the assumption that graphite would not yield in black-heart malleable iron. However, it certainly does yield over the irregularities projecting from its approximately spherical core. This may affect strains and stresses in the metallic matrix, and consequently the question of its yield would, also for this reason, require experimental studies.

The strain potential is distributed in such a way between the ferrite and cementite lamellæ in pearlite that yield does not seem to be possible at all. Regarding spheroidized steel, the unknown super-elasticity of ferrite controls the question as to whether or not tessellated yield develops spontaneously on cooling. Certain experimental observations concerning the damping of normalized and spheroidized specimens of one and the same chemical composition suggest an increased damping capacity of spheroidized steel, which, however, is evidence only of greater tessellated stresses existing in the ferrite of spheroidized than of normalized steel.

Tessellated yield has not been discussed in regard to martensite formation, though its occurrence may be expected with fair certainty. However, the complete lack of clues as to the yield resistance of nascent martensite suggests the postponement of this problem.

The study of tessellated yield offers a welcome opportunity for an extension of the previous analysis of the thermal expansion of tessellated compound bodies. If the compressibility $K = mE/3(m - 2)$ of each structural component of a compound sphere is the same, *i.e.*, $(m_o - 2)/m_o E_o = (m_i - 2)/m_i E_i$, a is found from equations (51b) and (51c) to equal $v_i a_i + (1 - v_i) a_o$ if the values of v_y lie between zero and $(1 - v_i)$. If $v_y = (1 - v_i)$, *i.e.*, if the whole matrix yields, equation (53) leads to the same result, provided that the compressibilities of the structural components are equal. Regarding lamellar tessellation it must be borne in mind that equation (44) accounts only for the component system of characteristic stresses. Equation (46), however, results from a special assumption which makes the lamellar units self-compensated, and it indicates once more that when tessellated yield occurs, equality of the compressibilities of the structural components makes the coefficient of thermal expansion of the compound structure equal to the proportional combination of the individual coefficients. The same relationship is guaranteed by the equality of the shear moduli of elasticity, if the change in temperature is so moderate that tessellated yield does not develop. For the perfect applicability of this rule over both the elastic and plastic ranges of straining, it is necessary that also the rigidities and compressibilities should be equal, *i.e.*, that the structural components should have elastic identity. If this is the case, it does not matter if the structural components do not behave perfectly elastically or perfectly plastically, since a stepped graph consisting of straight lines corresponding to perfect elasticity and plasticity may be substituted for the actual curved line relating stress and strain. However, the thermal expansivity of the compound body may also be affected if pure plastic shear is accompanied by volume changes in aggregates of one kind of crystal. Since actual knowledge on this point is far from being firmly established, let it be neglected for the time being. It is gratifying to note that the calculation of the individual thermal expansivities of ferrite and cementite in Part I., on which that of the cooling stresses in normalized and spheroidized steel is based, cannot be erroneous even if tessellated yield takes place on cooling or heating, unless it is proved that ferrite and cementite do not have fairly identical elastic constants or that their volume changes when subjected to pure plastic shear are not negligible. However, there is no reason to be found why tessellated yield which is not the consequence of a tessellated yield potential, *e.g.*, if caused by cold-working, should not affect the density of a body composed of materials having elastic identity.

It is shown in row 10 of Table XIX. that the coefficient of thermal expansion of spheroidized steel is independent of any development of tessellated yield. The tangential stress $f_{t,ss}$ in the ferrite midway between neighbouring cementite spherules is also invariable, unless the matrix yields over its whole mass. Since with the conditions underlying Table XIX. the matrix yields only in part, row 9 showing $f_{t,ss}$ is valid for yielding and unyielding units of the Table.

It is possible that on hardening steel, martensite as the matrix of retained austenite yields all over its mass, involving $s_{y,s} \neq 0$. Elastic identity of austenite and martensite would then require that $s_{y,s} + \frac{m_o - 1}{m_o E_o} f_y$ becomes a term independent of the yield resistance f_y of nascent martensite, and controlled, with regard to the present consideration, only by the actual volume fraction of retained austenite.

Tables XVI. to XVIII. contain confirmation of the suggestion made in Part III. that progressive tessellated yield would shift the thermal coefficient of the tessellated structure towards the figure obtained by the proportional combination of the individual coefficients. Graphite and ferrite, having greatly different compressibilities, offer a very favourable test case. The third line of row 4 of Table XVI., designated *p.c.*, contains the value of $a = u_o a_o + (1 - u_o) a_i$ for all weight percentages of graphite considered. These values should also be compared with rows 3 and 9 of Tables XVII. and XVIII. respectively.

The above investigation confirms also some further remarks in Part III. One of them referred to the possible hysteresis of thermal expansion. This would not occur in the case of structural components with equal compressibility or even elastic identity. Furthermore, from the above results it may be seen that compound structures which have undergone tessellated yield cannot release "elastically" the full amount of their elastic strain energy, and so would not become free from stresses without plastic stress redistribution occurring in addition.

RESHAPING OF STRUCTURAL COMPONENTS.

Changes in shape of structural components of invariable volume fraction are noticed in connection with many metallurgical processes. Let the discussion regarding the influence of tessellated stresses and yield be restricted to the process of annealing, unaffected by either transformation or recrystallization. In such cases, tessellated stresses develop exclusively owing to heating or cooling, provided that the individual thermal expansivities of the structural components are different, *i.e.*, the strain potential $\lambda = (a_o - a_i)t$ controls the process.

The principal feature of any reshaping process may be characterized as either spreading or compacting. It is suggested that the reshaping operations, *i.e.*, spreading *versus* compacting, should be analysed by comparing the strain energies of two compound spheres both consisting of a v_i volume fraction of *i* material and a $(1 - v_i)$ volume fraction of *o* material,

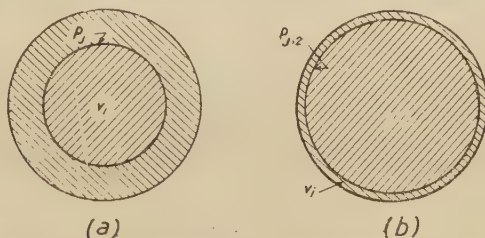


FIG. 19.—Standard (a) and Inverted (b) Arrangement of a Compound Sphere.

the *i* material being the core of the compound sphere in the one case, and the outer spherical shell in the other, as shown in Figs. 19 (a) and 19 (b), for the arbitrary value of $v_i = \frac{1}{4}$. Their analysis is given by equations (2) and (20) for Fig. 19 (a); for the inverted arrangement, *viz.*, Fig. 19 (b), equation (2) is to be modified by replacing p_j by :

$$p_{j,2} = \frac{\lambda}{\left(\frac{m_i - 1}{2m_i E_i}\right) \left(\frac{3 - 2v_i}{v_i}\right) + \frac{1}{m_i E_i} + \frac{m_o - 2}{m_o E_o}} \quad (54)$$

and its strain energy is to be calculated from :

$$U_2 = \frac{3}{2} \cdot \frac{m_o - 2}{m_o E_o} (1 - v_i) p_{j,2} + \left[\frac{9}{4} \left(\frac{m_i - 1}{m_i E_i}\right) \left(\frac{1 - v_i}{v_i}\right) + \frac{3}{4} \cdot \frac{m_i + 1}{m_i E_i} \right] (1 - v_i) p_{j,1} \quad (55)$$

Of the two "critical" arrangements of Fig. 19, that one will be fostered which involves less strain energy. Consequently, the magnitude of U for Fig. 19 (a) calculated with equations (2) and (20) is to be compared with that of U_2 for Fig. 19 (b).

Let a selective application of the index i be applied for the time being such that :

$$m_i E_i / 2(m_i + 1) = G_i > m_o E_o / 2(m_o + 1) = G_o$$

together with the notation of $G_i = G_o + D$ where $D > 0$. Furthermore, auxiliary use will be made of a pair of hypothetical compound spheres, according to Figs. 19 (a) and 19 (b), which consist of the unmodified o material of volume fraction $(1 - v_i)$, $G_o = m_o E_o / 2(m_o + 1)$ and $\epsilon_o = m_o E_o / (m_o - 1)$ and of a hypothetical material i, a of volume fraction v_i having elastic affinity to o such that :

$$\begin{aligned} G_{i, a} &= G_o = m_o E_o / 2(m_o + 1) \\ \epsilon_{i, a} &= \epsilon_i = m_i E_i / (m_i - 1). \end{aligned}$$

Regarding these auxiliary compound spheres, let the notations $p_{j, a}$ and U_a be introduced for an arrangement corresponding to Fig. 19 (a), calculated with equations (2) and (20) respectively, and for the inverted arrangement of Fig. 19 (b), the notations $p_{j, a2}$ and $U_{a, 2}$ corresponding to equations (54) and (55) respectively. Since the two materials o and i, a have elastic affinity, it follows that :

$$U_a = U_{a, 2} = \frac{\epsilon_i \epsilon_o v_i (1 - v_i)}{\epsilon_i v_i + \epsilon_o (1 - v_i)} \lambda^2 \quad . \quad . \quad . \quad . \quad . \quad (56)$$

Instead of comparing U and U_2 directly, they will be first related to the auxiliary values of U_a and $U_{a, 2}$ respectively. It is convenient to consider for the latter operation the following relationships between certain functions of the elastic constants of the materials involved :

$$\left[\frac{m_i + 1}{m_i E_i} \right]_a = \frac{1}{2G_o}; \left[\frac{m_i - 1}{m_i E_i} \right]_a = \frac{1}{\epsilon_i}; \left[\frac{1}{m_i E_i} \right]_a = \frac{\epsilon_i - 2G_o}{4\epsilon_i G_o}; \left[\frac{m_i - 2}{m_i E_i} \right]_a = \frac{6G_o - \epsilon_i}{4\epsilon_i G_o} \quad (57)$$

$$\left. \begin{aligned} \frac{m_i + 1}{m_i E_i} &= \frac{1}{2G_o} - \frac{D}{2G_o(G_o + D)}; \quad \frac{m_i - 1}{m_i E_i} = \frac{1}{\epsilon_i}; \\ \frac{1}{m_i E_i} &= \frac{\epsilon_i - 2G_o}{4\epsilon_i G_o} - \frac{D}{4G_o(G_o + D)}; \quad \frac{m_i - 2}{m_i E_i} = \frac{6G_o - \epsilon_i}{4\epsilon_i G_o} + \frac{D}{4G_o(G_o + D)} \end{aligned} \right\} \quad (58)$$

If i material is the core of a compound sphere and o material is the outer shell, it is found from equations (2), (57), and (58) that :

$$\frac{\lambda}{p_j} = \frac{\lambda}{p_{j, a}} + \frac{D}{4G_o(G_o + D)} \quad . \quad . \quad . \quad . \quad . \quad (59)$$

On expressing U and U_a by means of equation (20) but using the terms of equations (58) and (57) respectively, and considering equation (56) in addition, it is seen that :

$$\frac{U - U_a}{U_a} \left(\frac{\lambda}{p_j} \right)^2 = - \frac{D}{16G_o(G_o + D)} \left(6 \frac{\epsilon_i v_i + (1 - v_i)\epsilon_o}{\epsilon_i \epsilon_o (1 - v_i)} + \frac{D}{G_o(G_o + D)} \right) \quad (60)$$

Since $D > 0$, it is apparent that $U \leq U_a$ and that equality would occur only with $v_i = 0$ or $v_i = 1$.

If i material is the spherical shell and o material occupies the core position, equations (54), (57), and (58) lead to :

$$\frac{\lambda}{p_{j, 2}} = \frac{\lambda}{p_{j, a2}} - \frac{D}{4G_o(G_o + D)} \quad . \quad . \quad . \quad . \quad . \quad (61)$$

Next, U_2 and $U_{a,2}$ are to be expressed using equation (55) in terms of equations (58) and (57), and, with due regard to equation (56), it is found that :

$$\frac{U_2 - U_{a,2}}{U_{a,2}} \left(\frac{\lambda}{p_{j,2}} \right)^2 = \frac{D}{16\bar{G}_o(\bar{G}_o + D)} \left(6 \frac{\epsilon_i v_i + \epsilon_o(1 - v_i)}{\epsilon_i \epsilon_o v_i} - \frac{D}{\bar{G}_o(\bar{G}_o + D)} \right) \quad (62)$$

The sign of $U_2 - U_{a,2}$ depends on that of the bracketed difference on the right-hand side of equation (62). The first term of the bracket has the least possible value of $3/E_o$, which is obtained for any arbitrary value of E_o when $v_i = 1$ and $m_o = 2$. The maximum possible numerical value of the second term of the bracket is likewise $3/E_o$ and is obtained when D approaches infinity, and $m_o = 2$ as before. Consequently both the bracketed expression on the right-hand side of equation (62) and $U_2 - U_{a,2}$ are ≥ 0 , and $U_2 \geq U_{a,2}$, equality being possible only with either $v_i = 0$ or $v_i = 1$.

It is seen finally, since $U_a = U_{a,2}$, that $U_2 > U$ if $G_i > G_o$, and abandoning any convention regarding the relative magnitudes of G_i and G_o , the criterion of the reshaping effort of tessellated stresses reads :

$$\left. \begin{array}{ll} U_2 > U & \text{if } G_i > G_o \\ U_2 < U & \text{if } G_i < G_o \end{array} \right\} \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (63)$$

This means that tessellated stresses tend to spread (and convert to the matrix) the structural component with the lower shear modulus of elasticity and to compact, *i.e.*, spheroidize, the other.

It could of course be queried whether the above reasoning is sound and why shapes of increasing compactness, *viz.*, laminated cubes, compound cylinders and compound spheres of standard arrangement have not been compared with one another. Such an attempt did not seem advisable, since lamellar units and compound cylinders have not yet been analysed completely but only concerning the characteristic component system of tessellated stresses. However, this incompleteness of the analysis does not matter when the volume fraction of the i component is negligibly small. In such cases the strain energy of the compound body is proportional to the slope of the strain-energy/volume-fraction curve of the i component at the origin of the co-ordinate system, *viz.*, to $\left[\frac{dU}{dX_i} \right]_{x_i=0}$.

The value of this slope is found for laminated cubes with equations (8) and (19), for compound cylinders with equation (9) and the special strain energy equation for compound cylinders, and for compound spheres of standard and inverted arrangement respectively with equations (2) and (20) and with equations (54) and (55). It is then seen that :

$$\left[\frac{dU}{du_i} \right]_{u_i=0} = \frac{m_i E_i}{m_i - 1} \lambda^2 \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (64a)$$

$$\left[\frac{dU}{dw_i} \right]_{w_i=0} = \frac{\frac{3}{2} \cdot \frac{m_i + 1}{m_i E_i} + \frac{1}{2} \cdot \frac{m_o + 1}{m_o E_o}}{\frac{m_i + 1}{m_i E_i} \cdot \frac{m_i - 2}{m_i E_i} + \frac{1}{E_i} \cdot \frac{m_o + 1}{m_o E_o}} \lambda^2 \quad \cdot \quad \cdot \quad \cdot \quad (64b)$$

$$\left[\frac{dU}{dv_i} \right]_{v_i=0} = \frac{3}{2 \frac{m_i - 2}{m_i E_i} + \frac{m_o + 1}{m_o E_o}} \lambda^2 \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (64c)$$

$$\left[\frac{dU_2}{dv_i} \right]_{v_i=0} = \frac{m_i E_i}{m_i - 1} \lambda^2 \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (64d)$$

Since $\left[\frac{dU}{du_i} \right]_{u_i=0} = \left[\frac{dU_2}{dv_i} \right]_{v_i=0}$, it is noticed that the inverted sphere is a

correct substitution for the laminated cube, for $X_i = 0$. Furthermore a comparison shows that :

$$\left. \begin{aligned} \left[\frac{dU}{du_i} \right]_{u_i=0} &> \left[\frac{dU}{dw_i} \right]_{w_i=0} > \left[\frac{dU}{dv_i} \right]_{v_i=0} && \text{if } G_i > G_o \\ \left[\frac{dU}{du_i} \right]_{u_i=0} &< \left[\frac{dU}{dw_i} \right]_{w_i=0} < \left[\frac{dU}{dv_i} \right]_{v_i=0} && \text{if } G_i < G_o \end{aligned} \right\} \quad (65)$$

which indicates that in the effort to generate the least strain energy the i component is spread or compacted as its rigidity is smaller or greater respectively than that of o . This is in complete accord with the finding for the compound sphere of finite volume fractions of the components.

The strain energy due to a strain potential λ of an individual spherical particle of volume V which is embedded in an infinite matrix is $V \left[\frac{dU}{dv_i} \right]_{v_i=0}$.

Nabarro was concerned with this question and greatly in advance of the present author developed an equation² (*loc. cit.*, p. 521, equation (1)) corresponding to the above equation (64c).

The reshaping of structural components by annealing is effected by diffusion and plastic deformation, the reshaping potentials being stresses, *viz.*, surface tension and tessellated stresses. Surface tension, in its classical interpretation, would invariably try to reduce the total area of the junction between the structural components. This means gradual spheroidization and coarsening, combined with the effort to convert the structural component with the greater volume fraction into the matrix. It is unknown whether the modern view that there is some variation of the magnitude of the surface tension depending on which component has the concave surface, has any noticeable influence on the process of reshaping. Surface tension may therefore be considered as invariably tending to spheroidize and coalesce the structural component with smaller volume fraction and to convert the other into the matrix.

Tessellated stresses will develop if the thermal expansivities of the structural components are different, but they will display individual reshaping efforts only if their shear moduli of elasticity are also different, *i.e.*, $G_i \neq G_o$. Their efforts will then be selective in accord with equation (63), and independent in this regard of whether the stresses have been set up by heating or cooling, since equations (60) and (62) are independent of the actual signs of λ , p_j and $p_{j,2}$. Since tessellated stresses exert a selective effort, while that of surface tension is invariable in the above sense, the two reshaping potentials may be counterpoised in given cases, for instance, that of graphite in cast and malleable iron. Then the actual annealing temperature and the magnitude of the tessellated stresses will control the final issue as to which component will be spread and which compacted. Though tessellated stresses cannot display an individual contribution to reshaping if $G_i = G_o$, they may be beneficial as "agitators" when in conjunction with the reshaping effort of surface tension. If tessellated stresses are desired to assist the reshaping process continuously by annealing, pulsating heating suggests itself, since relaxation at the annealing temperature may more or less affect these stresses in the course of time.

These findings represent of course a considerable extension and modification of the views regarding pulsating heating which were voiced in Part I. on a less quantitative basis.

The question of relaxation is connected with that of tessellated yield. Whether one or both structural components yield and whether a yielding component is caused to spread or compact, depends on factors other than those influencing the reshaping effort of surface tension or tessellated

stresses. Regarding cast iron, it is seen that yield due to cooling stresses would compact the graphite lamellæ in opposition to the spreading effort exerted in a perfectly elastic tessellated process. Co-ordination of these efforts will, however, occur if heating-up is considered. If pulsating heating is applied and tessellated yield develops, its reshaping effect will be periodically reversed, *i.e.*, annulled. It may be suggested, on the one hand, that if the yield resistance of the structural components responds to a different extent to the time factor the application of different rates of periodic heating and cooling, and of different pauses at the limiting temperatures, may impede the reversal and cancellation and lead to some extent to additive and progressive reshaping, whilst, on the other, it seems doubtful whether heating which pulsates within rational limits would set up tessellated stresses noticeably exceeding the co-ordinated yield stresses, and justify the consideration of reshaping by tessellated yield in connection with pulsating heating; but these questions cannot be answered by theoretical analysis only. On cooling down from high temperatures to room temperature, however, tessellated yield may frequently develop, but its reshaping effect cannot be greater than the strain potential of that single cooling cycle.

Products of ferrous metallurgy usually pass through numerous heat treatment procedures. Simultaneous reshaping of the structural components, whether desired or not, is always connected with these procedures. Cast iron and malleable iron would deserve special experimental study in this respect. For intentional reshaping, the spheroidization of steel is the most conspicuous example in the whole of metallurgy. Tessellated stresses cannot, however, be of great importance if the rigidities of ferrite and cementite are really equal in the annealing range. Whether this is so has not been definitely established yet. The analysis of tessellated stresses and yield presented in this series of papers would greatly facilitate the precise investigation of the individual elastic constants and thermal expansivities of ferrite and other structural components of iron and steel if their tessellated compound bodies, having different volume fractions of the components, were tested for each volume fraction with both lamellar and spherical arrangements. As to the elastic constants, they should be derived from experiments with natural vibration, a method not yet duly appreciated and applied by metallurgical research.

PRECIPITATION-HARDENING.

Mott and Nabarro³ have attempted to find an explanation of precipitation-hardening by considering the stresses developing around an elementary particle of a spherical precipitate enclosed in an infinite matrix. Their mathematical analysis is a simplified version of equations (2) and (20) for the compound sphere (*see* Parts I. and II.). If such an analysis were to be attempted using statistical considerations, compound spheres should be imagined of an individual volume $1/N$, where N denotes the number of particles precipitated per unit volume. Each compound sphere then consists of a core of volume ξ_i , *viz.*, that of an individual particle of the precipitate, and of a shell of volume $(1/N - \xi_i)$. If the cohesive aggregate of such compound spheres is to be tested as to its hardness, its shear resistance is the critical feature. Let Fig. 19 (a) represent one single compound sphere. If this sphere is free from tessellated stresses, and it is distorted by shear through an interface passing through its centre, the shear resistance is with close approximation the proportional combination of those of its structural components, *i.e.* :

$$f_{s,i} \left(\frac{3\sqrt{\pi}\xi_i}{4} \right)^{\frac{2}{3}} + f_{s,o} \left[\left(\frac{3\sqrt{\pi}}{4N} \right)^{\frac{2}{3}} - \left(\frac{3\sqrt{\pi}\xi_i}{4} \right)^{\frac{2}{3}} \right],$$

where $f_{s,i}$ and $f_{s,o}$ denote the individual yield stresses in shear of the core and shell respectively.

If the same compound sphere is subsequently subjected to structural tessellated stresses of any magnitude, there is no reason to expect the slightest effect on its shear resistance as a whole along the interface considered above. The assumed tessellated stresses are self-compensated in that interface, and would not display any opposition to the shearing operation. Similar reasoning holds for any other interface of such compound spheres. Tessellated strains and stresses which existed before the attempted shearing operation should be considered to be ineffective in the direct sense with regard to the shear resistance of the compound body. This principal result applies also to any shape of tessellation other than spherical.

If reasons are to be found for the increased shear resistance of precipitation-hardened materials, they would be concerned with strains and stresses primarily involved in a shearing operation and directly generated by it. One of Nabarro's publications⁴ gives some indication where to look for such a reason. Nabarro investigated the stresses and strain energy involved in the precipitation of an elementary silver plate out of the solid solution with the copper matrix. It is assumed that precipitation takes place in (100) planes, and that the (linear) strain potential is about $\lambda = -0.12$, the negative sign denoting that silver requires an increased volume. The precipitate is consequently subjected to compression, and stresses and strain energy are calculated as if the matrix were not strained at all, and the precipitate were compressed only in its plane but not across its "thickness." Nabarro found the strain energy to be :

$$\delta U = \xi_i \frac{(c_{11} + 2c_{12})(c_{11} - c_{12})}{c_{11}} \lambda^2 \quad . \quad . \quad . \quad . \quad . \quad (66)$$

where ξ_i denotes again the volume of an individual particle of the precipitate, and c_{11} and c_{12} are the elastic crystal constants for silver as quoted in Part III.

This calculation is perfectly correct for the purpose for which Nabarro used it, but does not appear to be sufficiently accurate for the present case. Imagine the copper lattice to be "simplified" so that atoms exist only at the corners of the elementary cubes. Suppose then a lattice to be built up of helical springs substituted for the edges of the elementary copper cubes, the self-aligning joints of six springs representing the atoms. Let n^3 atoms be arranged tightly inside a cubic cavity, the latter having invariable dimensions. If n^2 copper atoms of one lattice plane (100), in the centre of the cubic cavity, should be replaced by silver atoms, let the effect be demonstrated by changing $2n^2$ copper springs of standard length for springs of 12% greater length and number of turns but otherwise unchanged. It must be expected that the silver springs would not only contract but would adopt a zig-zag arrangement relative to their (100) plane, i.e., the atomic arrangement would "buckle" in addition to the simple and now slightly reduced contraction of the silver springs. Since the sheet of silver atoms is connected, by springs at right angles to the silver plane (100), with the copper atoms of all parallel (100) planes, all the copper atoms will become displaced to alternate sides of their own (100) planes. The staggering of the copper atoms around their (100) plane will decrease with increasing distance of their plane from the silver plate, even if the walls of the cavity parallel to the silver plate allow for local staggering of the atoms. This gradually decreasing alternate dislocation of the copper atoms is controlled by the magnitude of the staggering of the silver atoms around their (100) plane, and the whole process of staggering is governed by the requirement that the least energy $\delta \bar{U}$ is involved regarding the whole

system of n^2 silver atoms and $(n^3 - n^2)$ copper atoms. The strains and stresses developing thereby over the whole system would not directly increase its resistance against shearing attempts along any interface in this case either. However, if shearing is attempted, say, along, or close and parallel to, the (100) plane of the silver atoms, the staggered atoms must be more or less completely forced back into their proper (100) planes during a slip equal to the atomic spacing. The average increase in resisting force is found from:

$$d \cdot \delta F = \eta(\delta U - \delta \bar{U}) \quad . \quad . \quad . \quad . \quad . \quad (67)$$

where δF , d , δU , and η denote respectively the increase in resisting force, the atomic spacing, the strain energy with unstaggered atoms corresponding to equation (66), and a factor ≤ 1 . It is of course well known that slip in copper-silver lattices does generally not take place in (100) planes. While the direct consideration of their fundamental slip planes (111) might have been rather complicated, it will now be recognized that if plastic shear were to develop the above argument regarding the necessity of a rectification of the positions of atoms which have suffered staggering displacements in consequence of the precipitation of nascent silver plates holds also for them. It may even be assumed that the actual planes and directions of a certain crystal lattice in which slip occurs are controlled among other factors by the strain energy required for such rectification.

Objection may be taken to the above qualitative considerations and attempts made to apply a scheme more in accordance with the terms and methods of theoretical physics. One can, however, hardly avoid arriving at something equivalent to the above suggestion of the staggering of atoms and at the consequent increased resistance of the lattice to plastic shear.

The precipitates of silver develop in three sets of parallel planes of the copper lattice, *viz.*, the (100), (010), and (001) planes, accompanied by three-dimensional staggering. Since the crystals are at random, the apparent increase in resistance to plastic shear will be uniform in every direction. Such an explanation of precipitation-hardening would of course also readily account for an increase in the hardening effect with increasing amounts of precipitate and with the increase in strain potential actually involved. The superior symmetry of cubic crystals should make them most suitable for precipitation-hardening. If the alternate staggering of the atoms is fairly great, their tearing-off may require little, if any, more effort than their forcing back into the unstaggered position. This would readily explain the brittleness accompanying pronounced precipitation-hardening.

The idea that a certain distortion of the lattice structure is the exclusive or complementary cause of some phenomena involved in the increase in hardness is fairly old. It has been frequently quoted as the "blocking of potential slip planes." The above reasoning does not contradict X-ray evidence either, since the diffraction patterns are made more or less diffuse by processes involving increase in hardness, and increasingly sharp by progressive softening.

The explanation suggested above restricts the possibility of efficient precipitation-hardening to conditions in which the atoms of a nascent precipitate are forced to occupy positions in the lattice of the matrix that are noticeably different from those which correspond to their own lattice spacing. If the gradual progress of precipitation increased the thickness of nascent plate-like precipitates so that the energy necessary for separating them from the lattice of the matrix ("breaking away"), together with the strain energy of tessellated stresses set up between matrix and precipitate (each having its individual lattice) was less than that of the nascent arrangement, then the atoms of the precipitate would rearrange

themselves in accordance with their individual lattices. This process would remove the previous increase in hardness, since not much staggering of atoms can be expected afterwards. The question of the breaking away of precipitates, without any reference to the staggering of atoms suggested, has been presented and analysed also by Nabarro.² The equation he developed, quoted as equation (66) in the present paper, has been utilized also in connection with the calculation of the thickness of nascent precipitates critical for their breaking away. From the point of view of precipitation-hardening it might be added that the increase to a critical thickness can be achieved not only by the gradual progress of precipitation, which was the only possibility mentioned by Nabarro, but also by compacting existing precipitates by annealing. This is of course a well-known phenomenon in metallurgy.

The system silver-copper is a fairly convenient one on which to base the explanation of precipitation-hardening by the staggering of atoms. If a similar attempt were made for cases where the individual nature and spacing of the lattices of the matrix and precipitate did not readily suggest the possibility of staggering, careful experimental and theoretical investigation might be required in order to find assumptions for the location of the atoms of the precipitate in the lattice of the matrix suitable for the degree of hardening observed and also compatible with X-ray evidence.

Finally, some further points suggest themselves in connection with the above discussion. Hard and brittle materials like martensite, cementite, or even diamond should be investigated as to whether with every elementary slip plastic shear would necessitate staggering modifications of the position of their atoms, *i.e.*, involve strains and strain energy of an indirect and more or less transverse character, in addition to their individual or common resistance. The analysis of this question as well as that of precipitation-hardening proper is accompanied by much complexity if the theorem of Taylor⁵ and Orovan⁶ is combined with the above consideration. The latter offers first of all an explanation of the relatively small resistance of ductile metals to plastic shear. With the Taylor-Orovan theorem included, it does not appear justified to restrict the factor η in an expression like equation (67) to values not exceeding unity. This means in general terms that the strain energy calculated per slipping atom for the displacement of atoms of more or less transverse character should turn out much greater if dislocation is considered to be involved in slip than if simultaneous slip of atoms across crystals is assumed.

The Taylor-Orovan theorem is also used as a basis for the explanation of strain-hardening. It may, however, be asked whether, or to what extent, periodic displacements of an indirect and more or less transverse character are involved individually if plastic shear is applied to strain-hardened material. Such displacements may readily account even for observations such as the slight reduction in hardness of metals if a certain degree of cold-working is exceeded.

MAGNETIZATION.

With regard to the previous discussion of tessellated stresses due to crystal anisotropy, magnetostriction suggests itself for consideration. However, on studying published data,^{7,8} it seems to be out of the question that consequential tessellated stresses could have a noticeable effect on the resistance to magnetization or that tessellated yield would develop and contribute in any way to the hysteresis losses. It may be considered to be a well-established fact that the above-mentioned magnetic phenomena are controlled by the effort required to turn the elementary magnets—which are, in a certain sense, at random in the virgin material—into

effective directions. This turning process involves tessellated stresses in elementary regions.

There is a certain similarity between the mechanism of magnetization and martensite transformation, if the latter is interpreted from the point of view of the processes involved in elementary regions. The term surface tessellation of Part I., which has been connected with the retention of austenite, may be replaced by a reference to "misfit" atoms, which are considered to exist between minute grains of retained austenite and the surrounding martensite matrix. The transformation of an individual grain of austenite would require, among other things, ample energy for a suitable rearrangement of the misfit atoms all around its enveloping surface. While this energy requirement is proportional to the surface area, the available energy is the product of the activation potential and the mass of the individual grain of austenite. If state (1) represents austenite and state (2) martensite, curves (a), (b), and (c) of Fig. 20 refer to transformations against increased resistance. The transformation of the finally retained austenite particles, having a very great ratio of surface area to mass, would involve curves towering so much above (c) that the requisite transformation potential cannot be generated in rational ways.

It has been noticed that the degree of magnetization of a permanent magnet may be increased if the sample exposed to the magnetizing field is tapped with a hammer. This suggests that there were numerous elementary magnets in their ineffective position before the application of the blow and that there might still be some after it. Fig. 20 may thus serve also for the representation of the process of magnetization, with the modification that (2) is allotted to the virgin condition and (1) to the magnetized state. It does not matter in this connection that magnetization is a reversible process whilst martensite formation is not. This comparison suggests of course the question whether or not the rate of approach to the maximum available magnetizing field strength has a noticeable effect on the saturation, similar to that of the rate of undercooling on the degree of transformation to martensite. Furthermore, it may be asked whether the above-mentioned interaction between mechanical strain and magnetization has a counterpart regarding hardening if carried out in a strong stationary or alternating field or under periodic magnetic shocks. Martensite formation may be accompanied by the formation of minute cracks, which contribute to the reduction in toughness, and it might be of interest to investigate whether this phenomenon may be influenced by magnetic forces applied during hardening. Their effect on the critical rate of cooling, on the proportion of retained austenite, and on the density might be studied at the same time. Finally, it may be asked whether the efficiency of permanent magnets is influenced by the martensite formation or the precipitation-hardening of the steel if these take place in different types of magnetic fields prior, of course, to magnetization.

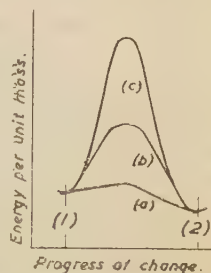


FIG. 20.—Activation Energy of the Austenite-Martensite Transformation.

INTERNAL FRICTION.

In connection with investigations on the internal friction of metals C. Zener⁹ mentioned locally self-compensated internal stresses due to crystal anisotropy, emphasizing their tessellated nature. Zener's considerations and experiments were restricted to thermo-elastic sources of

internal friction. One of them is the directional variability of the elasticity of single crystals. Plastic strain of any kind was excluded from Zener's experiments and the elastic body strain kept below 10^{-5} . It may be queried whether it is justified to describe such a phenomenon as internal friction. However, with regard to repeated remarks on damping and fatigue in Parts I. and II., it should be emphasized that only such damping as is generated by plastic strain may be critical from the point of view of the service performance of metals. Of course, strains of some higher order of magnitude than 10^{-5} are necessary to cause the metal to yield.

Minute plastic strains were involved in T. A. Read's¹⁰ experiments with single metal crystals, though the greatest strain which was applied, to a copper crystal only, amounted to not more than 4.1×10^{-5} , which would hardly develop noticeable plastic damping in any polycrystalline metal or be accompanied by fatigue failure. Nevertheless, Read's investigations deserve fair attention by metallurgists, also with regard to the scientific analysis of fatigue.

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REFERENCES.

1. F. LÁSZLÓ: *Journal of The Iron and Steel Institute*, 1943, No. I., p. 173 P; 1943, No. II., p. 137 P; 1944, No. II., p. 183 P.
2. F. R. N. NABARRO: *Proceedings of the Royal Society*, 1940, A, vol. 175, p. 519.
3. N. F. MOTT and F. R. N. NABARRO: *Proceedings of the Physical Society*, 1940, vol. 52, p. 86.
4. F. R. N. NABARRO: *Proceedings of the Physical Society*, 1940, vol. 52, p. 90.
5. G. I. TAYLOR: *Proceedings of the Royal Society*, 1934, A, vol. 145, p. 362.
6. E. OROWAN: *Zeitschrift für Physik*, 1934, vol. 89, p. 634.
7. W. L. WEBSTER: *Proceedings of the Royal Society*, 1925, A, vol. 107, p. 496; vol. 109, A, pp. 570 and 770.
8. K. HONDA and Y. MASIMAYA: *Science Reports of the Tôhoku Imperial University*, 1926, vol. 15, p. 755; 1931, vol. 20, p. 574.
9. C. ZENER: *Physical Review*, 1938, vol. 53, p. 90; *Proceedings of the Physical Society*, 1940, vol. 52, p. 152.
10. T. A. READ: *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1941, vol. 143, p. 30.

NOTE ON PART I.

The question of the nuclear effect of tessellated stresses of structural type was discussed on pp. 193 P–195 P of Part I. of the above paper (*Journal of The Iron and Steel Institute*, 1943, No. I.). This should have been done only with regard to the question whether a transformation process would result in a reduction of the strain energy associated with minute particles of slag, ferrite, or cementite. As indicated by equations 64a to 64d of Part IV., this would depend on whether the strain potential existing before the transformation would be reduced in its absolute value by the superposition of the strain potential individually involved in the transformation.

METHODS OF ASSESSMENT OF ANTI-FOULING COMPOSITIONS.*

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SYNOPSIS.

The colonization of a toxic surface immersed in the sea is dependent upon a number of factors, of which the most important may be termed the seasonal and the sensitivity factors. The former, imposed by the limited length of the breeding season of many marine organisms, expresses the availability of settling stages, spores or larvae, for settlement; the latter, produced by the varying sensitivities of these settling stages to the poisons released from the paint, governs the ability of the spores or larvae to settle and develop. Other factors play their part, but the sensitivity and seasonal factors are much the most important and any scheme of assessment which attempts critically to assess the performance of an anti-fouling composition, should be based on these two factors.

The present paper gives an account of a method of assessment which attempts to allow for these factors. The wide range of sensitivity of the animals and plants commonly settling on exposed panels has enabled a fouling sequence to be constructed and this is used, with due allowance for seasonal effects, as a means of placing anti-fouling compositions under test in one of five categories, which represent five stages of increasing inadequacy of protection against fouling. This method has given satisfactory results with a large number of exposures of experimental anti-fouling compositions but, since it is an evaluation of a series of biological inter-relationships, it cannot always be rigidly applied. To some extent, each case must be treated on its merits, and examples are given of detailed assessments which illustrate difficulties or points of particular interest in the application of the method.

I.—INTRODUCTION.

ANY stable object immersed in the sea will become colonized by a variety of marine organisms. The types of organism which settle and the rapidity with which colonization takes place depend upon a number of factors. The exposed surface must be of a suitable type and in a suitable state for settlement to occur; the appropriate settling stages, spores or larvae, must be available and, once settlement has occurred, the extent of colonization and growth is governed by a group of environmental factors, of which light, with its potent effects on the amount of plant growth, is perhaps the most striking. In the later stages of colonization, the characteristics of the organisms which have already settled add a further factor which may markedly influence the type and extent of later settlement.

If the surface immersed is toxic, the importance of its type and state is enormously increased. When a non-toxic or inert surface is immersed in sea-water, a short interval elapses before extensive colonization begins, but if the surface exposed is of the type commonly provided by an anti-fouling composition, this interval is considerably prolonged. Such a surface is releasing poisons into the water at a rate which depends upon

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the type of composition employed and the period for which it has been immersed.

The plants and animals which are capable of settling on a non-living surface differ widely in their sensitivity to the poisons (copper and mercury) commonly employed in anti-fouling compositions, and this *sensitivity factor* is a rigorous control of the type and extent of settlement that can occur on a surface coated with such a composition. Indeed, it may be said that this factor and the *seasonal factor* imposed by the limited breeding periods of many fouling organisms are the most important conditions governing the extent of colonization and fouling that may take place. Any scheme of assessment which is to give a critical evaluation of the performance of an anti-fouling composition must be based on these factors, and in this paper an account is given of a scheme which it is believed represents a step in this direction.

II.—METHOD OF EXAMINATION AND BASIS OF ASSESSMENT.

Before giving an account of the sequence of fouling organisms which have been observed to occur on an anti-fouling paint as the leaching rate of the contained poisons decreases, it is perhaps appropriate briefly to outline the conditions under which assessments are made and the basis on which ratings are given.

Painted panels are examined and assessed under water in a shallow wooden trough. This method of examination enables the various types of fouling organism to be readily distinguished and, as the possibility of damage to the paint film due to partial drying of the surface is eliminated, examination can be extended as long as necessary. It has been found convenient to make examinations at approximately monthly intervals.

In the earliest stages of exposure, samples of the fouling (chiefly, at this stage, bacterial slime and diatoms, possibly with sporelings of the larger fouling seaweeds) are removed for microscopic examination by means of small rubber scrapers, held in a pair of forceps. Later in the exposure, as macroscopic fouling develops, this procedure is usually not necessary.

Each fouling organism that can be recognized macroscopically is rated separately. Ratings are given on a geometrical scale, from 0 to 7, with the addition of a "trace" rating, given to record the presence of organisms in numbers too small to be rated, but which may be important as indicators of the adequacy of protection offered by the paint under examination. In terms of frequency, the steps of the rating scale roughly correspond to the following categories :

Rating.	
1	Very rare.
2	Rare.
3	Occasional.
4	Frequent.
5	Very frequent.
6	Abundant.
7	Very abundant.

The utilization of a scale of ratings from 0 to 7 perhaps merits brief comment. This range of values has developed as the work on assessing anti-fouling compositions has been extended. Initially a scale of four steps was used, but it was soon found desirable to introduce ratings between zero and the lowest rating of this limited scale and for a time fractional ratings were introduced to bridge this gap. This rather clumsy notation was later modified to give the 0-7 scale at present in use. There is thus no special significance in this choice of scale, but it is one which has proved satisfactory in use. Other investigators may wish to adopt a different scale; in this connection it might be added that experience with the scale used in this scheme suggests that a modification which slightly increased the

number of terms in the progression (*e.g.*, the adoption of a scale of ratings from 0 to 10) would have advantages over a modification which reduced the number of these terms.

The rating scale is based on numbers of organisms settled and not on their size or specifically on the area which they cover. It seems logical to base ratings on this criterion, in that it emphasizes settlement rather than growth. Though the rate of growth of a fouling organism may be influenced by the toxicity of the surface on which it has settled and though a well-grown or fully developed organism, in that it offers greater resistance to the movement of the fouled surface through the water, is a more serious problem from the practical aspect, the critical period for an assessment of the paint is that at which settlement becomes possible. This is the period at which the composition exposed is ceasing to give adequate protection and one which any critical scheme of assessment should determine as accurately as possible.

Many of the exposures of experimental anti-fouling compositions have been made on patch-painted panels, each face of each panel being subdivided into a number of equal areas, each of which receives a coat of a different anti-fouling composition. Panels 2 ft. square, each face divided into six patches, each 12 in. across by 8 in. deep, have commonly been used. This method enables a number of compositions to be tested within a limited space and, as each composition is exposed at least once on each face and the arrangement of the compositions is made random, this provides a fair trial of each composition. The poisons released from a highly toxic composition may affect the development of fouling on those parts of a less toxic neighbour immediately adjacent, but such "border effects" are clearly recognizable when they occur and are rarely extensive.

III.—THE FOULING SEQUENCE.

The description of the sequence of fouling forms given in this section is based almost entirely on experience gained from raft exposures made at Millport, in the Firth of Clyde. The sequence outlined can apply strictly only to exposures made in this locality, but there is no reason to suppose that conditions in the Clyde are, in any important respect, abnormal, and it is probable that a similar sequence will be found to occur at many points round the coasts of the British Isles.

In an earlier publication,¹ attention was drawn to the structure of the community which colonized a painted surface and a description was given of the various layers, basal carpet, filamentous, shrub, and tree layers, into which it could be divided. At first, detailed assessments were made along these lines, but it later became apparent that this conception, although providing information of interest to the plant or animal ecologist, contained detail irrelevant to the main problem at issue, *viz.*, the evaluation of the paints under test. As information on the varying sensitivities of different plant and animal fouling forms began to accumulate, it became evident that attention should particularly be focused on the occurrence of the different fouling forms and less emphasis laid on their arrangement and inter-relationships. Thus in the scheme of assessment presented in the present paper, little account has been taken of the layers of the community, the ratings given including individuals of all sizes. As in both schemes of assessment, ratings of individual organisms have always been given, it will be realized that the data accumulated under the earlier, more complex, scheme can be readily re-interpreted for use in this later scheme immediately to be described.

The animals and plants commonly settling on submerged surfaces differ markedly in their sensitivity to heavy-metal poisons such as copper and

mercury. It is therefore possible to arrange these organisms in a sequence ranging from the least sensitive forms, which can settle on a surface which is toxic enough to prevent settlement of all other forms, to the most sensitive organisms, which can settle only when the exposed surface is virtually non-toxic. This sequence is given in Table I., in which the broken line indicates the boundary between adequate and inadequate protection against fouling. Exposed panels carrying organisms listed above this line in Table I. are rated as unfouled; those carrying organisms listed below this line are rated as fouled.

This sequence of fouling organisms is built up from analyses of the settlement occurring on experimental compositions and on the basis of laboratory determinations of sensitivity. In drawing up this sequence rather more attention has been paid to the first source of information than to the second, since a laboratory determination of sensitivity, in which the organism is wholly bathed in the toxic solution, does not completely reproduce field conditions, where only that part of the organism on, or immediately adjacent to, the paint is bathed in a toxic environment. Miss F. A. Stanbury (Plymouth) has determined the sensitivities of a wide range of fouling diatoms and other algae and the results of her determinations substantially agree with the sequence quoted in Table I.

TABLE I.—*The Fouling Sequence.*

Toxicity of Surface.	Sensitivity of Organism.	Plant.	Animal.	Protection.
High.	Low.	D. Amphiprora.		↑
		D. Schizonema.		Adequate.
		GW. Ulothrix.		
		D. Achnanthes.		↓
		BW. "Brown Mats."		↑
		GW. Enteromorpha.	H. Tubularia.	
		BW. Ectocarpus.	B. Balanus.	Inadequate.
		D. Fragilaria.	H. Obelia.	
		RW. Ceramium. }		
		RW. Polysiphonia. }		
		GW. Cladophora.		
		BW. Laminaria. }	TW. Pomatoceros. }	
		BW. Punctaria. }	M. Mytilus. }	
		BW. Desmarestia. }	M. Anomia. }	Nil.
		GW. Ulva, &c. }	M. Pecten. }	
			AM. Jassa. }	
			P. Membranipora. }	
			A. Didemnum, &c. }	↓
Low.	High.			

KEY.

A. Ascidian (sea squirt).
 AM. Amphipod.
 B. Barnacle.
 BW. Brown weed.
 D. Diatom.
 GW. Green weed.

H. Hydroid.
 M. Mollusc.
 P. Polyzoan.
 RW. Red weed.
 TW. Tube worm.

Though the information given in this table is, it is hoped, self-explanatory, one or two points merit further comment.

It will be seen that no mention is made of bacterial slime. Although the settlement of slime-secreting bacteria is frequently the first organic settlement to occur when a painted surface is immersed in sea-water, experience of raft exposures has confirmed the conclusion, drawn by Dr. M. F. Mare from her work on bacterial slimes, that "there is no simple correlation between slime formation and anti-fouling efficiency." Recent American work² has shown that sea-water contains bacteria which are able to withstand concentrations of copper as high as 500 mg. of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ per litre of medium; in view of this high degree of tolerance of one of the poisons most frequently incorporated in anti-fouling compositions, it is not surprising that the development of bacterial slime is no safe guide to the anti-fouling properties of a composition under test.

The resistance of some plant fouling organisms to poisons (particularly the green weeds *Ulothrix* and *Enteromorpha*) is markedly affected by variations in light intensity. When the light intensity is high, resistance is greater. This factor affects the position of these organisms in the fouling sequence (when the light intensity is high both *Ulothrix* and *Enteromorpha* may be placed above the diatom *Achnanthes*). Thus a composition must have a higher leaching rate to prevent settlement of these organisms under conditions where the light intensity is high.

The most resistant macroscopic plant fouling organisms (and thus the first to appear on the surface of a paint which is just failing to maintain an adequate leaching rate) are growths which have been termed, colloquially, "brown mats." These are small, brown, disc-like growths which, on microscopic examination, are seen to be formed by a filamentous brown alga. Detailed examination in this way indicates that many of these growths are formed by the brown alga *Ectocarpus*, though on one occasion this type of growth has been identified (by Professor F. E. Fritsch) as the brown weed *Hecatonema globosum* Batt. This type of growth appears to be more resistant than more normally grown specimens of *Ectocarpus*, but its identity is still doubtful. At present, the possibilities seem to be:

(a) That these structures are an early stage in the development of *Ectocarpus*; a stage in which the basal attachment system is well developed, but which does not yet possess the branched stems characteristic of the fully developed weed.

(b) That these structures are a stunted form of *Ectocarpus*; an abnormal type of growth produced in response to the abnormal environment of the surface of an anti-fouling composition.

(c) That these structures are formed only by the brown alga, *Hecatonema globosum*.

Evidence is lacking on which to discriminate between these possibilities, but it can be stated that the third possibility is very unlikely to be true, as *Ectocarpus* is certainly associated with many of these growths. Much critical work would be necessary to clarify the position completely, but these growths have been such a typical feature of the fouling occurring on panels exposed at Millport that their inclusion in the fouling sequence seems warranted, in spite of the doubt as to their identity. In Table I. *Ectocarpus* refers to normally grown specimens of this alga; such specimens appear to be less resistant than the "brown mats" just described.

The only animal fouling form given in Table I. which calls for comment is the acorn barnacle (*Balanus*). This is shown as a moderately resistant form, slightly less resistant than *Ectocarpus*, though this placing refers only to barnacles which have metamorphosed and are growing. Settlement and metamorphosis can take place on surfaces too toxic to allow the meta-

morphosed form to persist; such individuals die and usually become detached at an early stage. Assessments of barnacle fouling made immediately after a settlement may thus give a false impression of the degree of protection given, but this impression is corrected in later assessments.

IV.—INTER-RELATIONSHIPS OF ORGANISMS WITHIN THE FOULING SEQUENCE.

The fouling sequence described in the previous section can rarely, if ever, be realized in its entirety under normal conditions of exposure. It is a description of the fouling that would occur provided that:

(a) Settling stages of all the organisms described were available throughout the year.

(b) The leaching rate of the poisons incorporated in the paint decreased sufficiently slowly to allow each step in the sequence to be fully shown.

(c) The settlement of one organism would not interfere with the subsequent settlement of others.

Such conditions are clearly unattainable. The fouling that may occur on a paint surface depends upon the toxicity of the surface, the time of the year, and the fouling forms already present. In Table II. an attempt is made to summarize the chief factors concerned in the inter-relationships between members of the fouling sequence listed in Table I. These factors are summarized under four headings:

(a) *Settlement*.—This is the period over which settling stages, spores or larvae, are available. It will be realized that these data apply particularly to Millport; some modification in season may occur at other exposure sites.

(b) *Occurrence*.—This is an expression of the length of life of an organism. Some organisms which have a limited settlement period may live long enough to occur on exposed panels at all seasons, e.g., *Balanus balanoides*, which settles at Millport only during April yet, once settled, will continue to occur throughout the year. In the case of micro-organisms such as diatoms and bacteria, it will be clear that, though the life period of any individual may be much shorter than the period of occurrence given in the table, the rate of reproduction *in situ* is high enough to give the appearance of an extended period of occurrence.

(c) *Aggression*.—The aggressive tendencies of a fouling organism determine the extent to which it is capable of ousting other forms. Highly aggressive species give rise to the most striking cases of the phenomenon of *biological exclusion* mentioned in the Sub-Committee's First Report.³

(d) *Persistence*.—The extent to which an organism is able to withstand competition from other, particularly the more aggressive, members of the community.

All these factors must be considered when analysing the results of assessments, but it is suggested that, provided these factors are taken into account, the fouling sequence outlined in Table I. gives a fair interpretation of the stages of fouling that can occur. Further work may modify this sequence but not, it is thought, in any important respect.

This fouling sequence can be most completely used where it is possible to make assessments under water, since under these conditions individual fouling organisms can be recognized with reasonable ease. It is possible, however, to recognize many of the organisms given in Table I. in a semi-dry condition, so that even where under-water examination is not practicable, this fouling sequence can be used even if it is limited to the recognition of a few critical forms, which either indicate that the paint is no longer giving complete protection (e.g., *Tabularia*, "Brown mats," or *Ectocarpus*)

or which indicate a virtual lack of toxicity (e.g., *Pomatoceros*, *Laminaria*, &c.).

TABLE II.—*Biological Characteristics of Fouling Organisms.*

Organism.		Settlement.	Occurrence.	Aggression.	Persistence.
Type.	Generic Name.				
D.	<i>Amphiprora</i> .	Mar.-Sept.	Mar.-Sept.*	Nil.	Low.*
D.	<i>Schizonema</i> .	Jan.-Dec.	Jan.-Dec.	Nil.	High.
GW.	<i>Ulothrix</i> .	Mar.-Oct.	Mar.-Oct.	Nil.	Low.
D.	<i>Achnanthes</i> .	Jan.-Dec.†	Jan.-Dec.	Nil.	Fair.
GW.	<i>Enteromorpha</i> .	Jan.-Dec.	Jan.-Dec.	Very high.‡	High.
H.	<i>Tubularia</i> .	May-Nov.	Dies off.§	Fair.	High.
BW.	"Brown mats."	Jan.-Dec.	Jan.-Dec.	Nil.||	Very high.
BW.	<i>Ectocarpus</i> .	Jan.-Dec.	Jan.-Dec.	Nil.	Very high.
B.	<i>Balanus</i> .	Apr.-Sept.**	Jan.-Dec.	High.	Fair.†† High.‡‡
D.	<i>Fragilaria</i> .	Apr.-Oct.	Apr.-Oct.	Low.	Variable; high in mid-season.
H.	<i>Obelia</i> .	June-July.	June-Aug. (dies off).	Fair.	High.
RW.	<i>Ceramium</i> .	Jan.-Dec.	Jan.-Dec.	Nil.	Fair.
RW.	<i>Polysiphonia</i> .	Feb.-Sept.	Feb.-Sept.	Nil.	Fair.
GW.	<i>Cladophora</i> .	Jan.-Dec.	Jan.-Dec.	Nil.	High.
BW.	<i>Laminaria</i> .	Dec.-Mar.	Jan.-Dec.	High.§§	High.
BW.	<i>Punctaria</i> .	?May-Aug.	?May-Aug.	Fair.	High.
BW.	<i>Desmarestia</i> .	Apr.-May.	Apr.-?July.	Fair.	Fair.
GW.	<i>Ulva</i> .	Jan.-Dec.	Jan.-Dec.	Low.	Fairly high.
TW.	<i>Pomatoceros</i> .	June-Sept.||||	Jan.-Dec.	Low.	High.
M.	<i>Mytilus</i> .	July-Sept.***	Jan.-Dec.	Very high.	Very high.
M.	<i>Anomia</i> .	Aug.-Sept.	Jan.-Dec.	Nil.	Fair.
M.	<i>Pecten</i> .	Aug.-Sept.	Aug.-Mar.†††	Nil.	Fair.
C.	<i>Jassa</i> .	July-Sept.	?Jan.-Dec.	Fair.	Fairly high.
P.	<i>Membranipora</i> .	June-Sept.	Jan.-Dec.	Very high.	Very high.
A.	<i>Didemnum</i> .	June-Sept.	Jan.-Dec.	Very high.†††	Very high.

* Settlements of this diatom appear to have a limited life, but as an extensive settlement can occur only on a toxic surface, the poisons leached from the latter may produce this effect.

† Settlement is appreciably less in midsummer (May to September).

‡ At high light intensities.

§ The polyps of this hydroid die off rather rapidly and also die down in the autumn; the colonies can persist through the winter and again produce polyps in the spring.

|| Though these growths are not aggressive in the sense that their rapid growth and development leads to the death and exclusion of other members of the community, certain types of anti-fouling composition allow an extensive settlement of this kind of growth, so that the surface of the paint becomes covered with a dense mat of filaments. Few other fouling forms will settle on this surface.

** *Balanus balanoides* settles in April; *B. crenatus* from late April through May to September.

†† Young metamorphosed specimens.

‡‡ Older metamorphosed specimens.

§§ The growth rate of this brown alga is extremely rapid (of the order of 1 ft./month) and its long, leathery fronds, sweeping over the surrounding paint surface, may prevent the settlement of other fouling forms within the area covered by this movement.

|||| The main period of settlement; it is usually preceded by a small settlement in April.

*** This settlement period is that of the young larvae. Older individuals are also capable of migrating on to raft-exposed surfaces. This migration can take place at any time of the year.

††† This period of occurrence was recorded in 1944-45, but may be abnormally prolonged. August to December may be the more normal period.

†††† Possibly the most aggressive of the fouling forms listed. Under favourable conditions rate of growth is very rapid and the gelatinous sheet formed by this organism rapidly smothers any growth beneath it.

V.—ANALYSIS OF ASSESSMENTS.

The ideal treatment of the results obtained from the assessment of individual organisms would be to correct the observed rating by factors which allowed for the sensitivity of the organism concerned and for the time of the year at which the assessment was made. Comparison could then be made between the total of the corrected ratings for each organism present for the paint under test and a figure obtained by the application of this treatment to the ratings given for a non-toxic surface exposed for the same period and at the same time.

Laboratory determinations of sensitivity, together with analyses of the fouling on raft-exposed panels have enabled the correcting factor for

sensitivity to be roughly determined, but it seems doubtful whether the correcting factor for season could ever be firmly established. In the First Report⁴ a diagram was given of the seasonal settlement of fouling organisms and this diagram was repeated, with slight modifications, in a more recent publication.⁵ Such diagrams indicate the general abundance of the various types of fouling organisms at various seasons, but for a seasonal correcting factor more detailed information is necessary. If seasonal records are examined in greater detail, it is immediately evident that the abundance of any given organism may vary widely from year to year; for example, the settlement of *Balanus balanoides* was light at Millport in 1943, heavy in 1944, and fairly heavy in 1945; *Balanus crenatus* was settling in some numbers in June and July 1943, but was virtually absent in the corresponding months of 1944; *Pecten* (both *P. maximus* and *P. opercularis*) did not settle in 1942 or 1943, but settled in some numbers in 1944; the diatom *Fragilaria* was abundant during June, July, and early August 1942, was frequent during midsummer 1943, but much less common in the following summer; the red alga *Antithamnion* was moderately common in 1942, virtually absent in 1943, and present only in small amounts in 1944. Thus the seasonal correcting factor would have to be evaluated afresh each season, to ensure that it allowed, not only for the general seasonal variation but also for the particular conditions applying through any one season.

Work on the determination of seasonal correcting factors has been begun, but in view of the difficulties just mentioned, a method of analysis has been adopted which, while not giving such precise results, does, it is hoped, add detail to the picture given of the anti-fouling performance of a composition under test. By following this scheme, a paint can be placed, on the basis of the extent and type of its fouling, in one of five categories. These five categories are defined and described below. As preface to this description, it should be stated that mean rating values of less than one are in general neglected, since the record of traces of an organism may be misleading, as small settlements may take place which are influenced by factors other than toxicity of the surface.

The five categories used, and the symbols used to denote them, are as follows:

(1) *Symbol 0*. Paints unfouled, or fouled with diatom only (at Millport, paints in this category are almost always fouled with *Amphiprora*. *Achnanthes* may be present in small amounts, but paints fouled with this diatom almost invariably—for other reasons—fall into the next category.).

(2) *Symbol Ö*. Paints fouled with diatom (often *Amphiprora* and *Achnanthes*, sometimes *Achnanthes* only); with *Ulothrix* (this alga usually appears, on paints at this stage, as short filaments, closely associated with the diatom slime and giving a green colour to the latter) and with non-significant ratings (up to 1) of the most resistant of the larger fouling organisms (chiefly *Tubularia*).

(3) *Symbol f*. Diatom and *Ulothrix* fouling may still be present, but the characteristic feature of the fouling of paints in this category is the presence of the larger resistant fouling organisms ("Brown mats" *Tubularia*, *Enteromorpha*) in significant amounts. Traces of less resistant forms (specified in the section below) may also be present.

(4) *Symbol F*. Resistant forms may still be present, but significant quantities of forms only moderately resistant (*Ectocarpus* and possibly *Fragilaria*; *Balanus* and *Obelia*) are characteristic of paints in this category. Diatom and *Ulothrix* fouling is less conspicuous, being largely eliminated or obscured by the growth of these other forms.

(5) *Symbol FF*. Paints which are heavily fouled, often with a variety of organisms, including one or more of the most sensitive types characteristic of paints which are virtually non-toxic.

If analysis of the fouling present on the surface of a composition indicates the inclusion of the composition in either of the first two categories, it is deemed to be offering adequate protection and is considered to be unfouled. If the paint is included in the third, fourth, or fifth categories, it is considered to be fouled and the protection offered is increasingly inadequate. It will be evident that these categories are not sharply distinct, and it is sometimes convenient to use a combination of two categories to denote the fouling state of a composition, *e.g.*, f/F which indicates that, though the fouling present warrants inclusion in the third category (f) there are indications that less resistant organisms are spreading and that inclusion in the fourth category (F) will soon be justified.

If the fouling state of a paint is O and f at successive assessments, the anti-fouling life is estimated as ending midway between the two assessment dates; if the fouling state on assessment is O/f or O/F , this is regarded as the time at which the paint ceases to give adequate protection, provided that later assessments show that the paint has become fouled.

The differentiation of categories below the level at which a paint ceases to afford adequate protection may seem to be only of academic interest and for the routine testing of anti-fouling compositions this is certainly true. Many assessments are made, however, of experimental compositions where information from raft exposures, not only of the failure of a composition by fouling, but also of the degree of failure may be important additional evidence for the chemist and paint technologist and a valuable guide in later formulations.

Some examples, chosen both from proprietary and experimental compositions, are given below of assessments made according to this scheme, with explanatory notes on points of interest in the assessment or its analysis.

(a) *Composition Containing Copper Only with a Moderate Anti-Fouling Life.*

In this and the following examples only the critical period of assessment is quoted in full.

TABLE III.—*Assessments of Composition Containing Copper Only with a Moderate Anti-Fouling Life.*

Fouling Organism.*	Mean Ratings after Exposures of (days):			
	125.	157.	188.	213.
Diatom	2.0 †	3.5	1.0	1.5
"Brown mats" . . . . .	...	...	0.5	2.5
Ectocarpus . . . . .	...	Trace	1.0	2.5
Balanus . . . . .	...	1.0	Trace	Trace
Fragilaria . . . . .	...	...	...	0.5
Obelia . . . . .	...	...	...	Trace
Fouling state	0	O	O/F	F

* The fouling organisms are quoted in this and in the following Tables in the order given in Table I.

† Raft assessments of diatom settlements are rated as "Diatom," without regard to the genus present, but samples are removed for later microscopic investigation. In this case the diatom present was *Amphiprora*.

In the series of assessments given in Table III. the composition could strictly have been rated as fouled on the results of the inspection at 157 days. The fouling state was given as O because *Balanus* was the critical

organism present upon which the paint would have been condemned. As *Balanus* can die off after settlement and metamorphosis have occurred, a composition should not be rated as fouled on ratings of this organism for a single inspection; in this case it will be noted that some of the barnacles recorded at 157 days had disappeared at the next assessment.

The fouling state at the next inspection (188 days) is still rather questionable, though strictly the composition should be regarded as fouled. The results of a further assessment (at 213 days) indicate that the composition had then quite definitely ceased to give adequate protection.

The length of anti-fouling life of this exposure is not greater than 200 days and may be as short as 170 days.

This composition shows the beginnings of a type of fouling that has proved particularly characteristic of compositions which contain copper as their effective poison. The fouling which develops on such compositions is characterized by the extensive settlement of "Brown mats," together with some development of *Ectocarpus*. This growth of brown algae rapidly covers the paint surface with a dense felt of short, filamentous branches, among which planktonic and neritic diatoms soon become entangled; when this type of fouling is well developed, the whole paint surface is covered with a dense, dark-brown felt of algal filaments. It is a type of fouling that develops equally well on proprietary and experimental compositions and which can develop at any time during the fouling season. It would seem that, when the rate of loss of poison (from a composition containing copper only) drops below the critical value, the decrease in rate is slight, so that the paint surface remains in a sufficiently toxic condition long enough for such moderately resistant types as *Hecatonema* and *Ectocarpus* to settle and spread. This felt of algal filaments is evidently an unsuitable substratum for further settlement (from observations at Millport, only *Tubularia* and *Jassa* seem able to settle on this surface), so that the fouled surface may remain in this state for a considerable period.

(b) *Compositions with Short (or Negligible) Anti-Fouling Lives.*

Details are given in Table IV. of the assessments of two compositions (*A* and *B*) which proved to be unsuccessful; the first of these has a short anti-fouling life, the second has no anti-fouling properties of any significance. The fouling ratings for non-toxic areas, exposed over the same period, are included for comparison.

At the inspection, after 29 days' exposure, composition *A* is virtually unfouled, though the presence of traces of *Obelia* suggests that continued exposure may lead to heavier fouling. This suggestion is certainly borne out at the next inspection (61 days' exposure), where the presence of *Ectocarpus* and *Obelia* place the composition in the fourth category (*F*) and where the presence of traces of such sensitive organisms as *Pomatoceros* and *Membranipora* suggest a virtual lack of toxicity, so that the fouling state of this composition at this stage can be stated to be *F/FF*. At the next inspection (after 101 days' exposure, not given in Table IV.), the fouling category was *FF*. The anti-fouling life of composition *A* is thus of the order of 45 days.

The fouling which had settled on the second composition (*B*) after 29 days' exposure is closely similar, both in type and amount, to that on the non-toxic areas. This, coupled with the presence of *Pomatoceros*, indicates lack of toxic properties and suggests inclusion in the fifth category (*FF*). Composition *B* thus lacks any anti-fouling properties.

(c) *Composition with a Long Anti-Fouling Life.*

This series of assessments is included as an example of a difficulty which may be encountered in determining length of anti-fouling life because of

TABLE IV.—*Assessments of Compositions with Short (or Negligible) Anti-Fouling Lives.*

Fouling Organism.	Mean Ratings.					
	Composition A.		Composition B.		Non-Toxic Area.	
	29 days' Exposure.	61 days' Exposure.	29 days' Exposure.	61 days' Exposure.	29 days' Exposure.	61 days' Exposure.
Diatom . . .	...	...	...	...	0.5	Nil
Ulothrix . . .	...	...	1.0	...	1.5	...
Tubularia . . .	...	2.5	...	1.5	...	1.0
Ectocarpus . . .	...	2.5	...	...	...	0.25
Balanus . . .	...	Trace	...	1.0	...	0.5
Fragilaria . . .	0.5	...	2.0	...	2.5	...
Obelia . . .	Trace	1.4	0.5	3.0	0.75	3.5
Ceramium . . .	...	...	...	...	...	Trace
Ulva . . .	...	...	...	...	...	Trace
Pomatoceros . . .	...	Trace	1.0	2.5	1.5	3.25
Anomia . . .	...	...	...	Trace	...	Trace
Membranipora . . .	...	Trace	...	Trace	...	...
Didemnum . . .	...	...	...	Trace	...	...
Fouling state . .	O	F/FF	FF	FF	FF	FF

TABLE V.—*Assessments of Composition with a Long Anti-Fouling Life.*

Fouling Organism.	Mean Ratings after Exposures of (days) :						
	86.	134.	285.	312.	433.†	456.†	491.
Diatom . . .	1.0 *	3.0	2.5	2.5	...	...	0.5
Ulothrix . . .	...	1.0	...	...	...	...	...
Tubularia . . .	...	...	1.0	Trace	...	...	Trace
Balanus . . .	...	...	...	...	...	...	6.0
Fouling state . .	O	O	O	O	O	O	F

* The diatom present was *Amphiprora*.

† These were winter assessments. During this season, when little change in fouling present can be detected from month to month, detailed ratings were not given; inspection was made and only the fouling state recorded.

lack of fouling at the critical part of the exposure period. Only a selection of the assessments made are given in Table V.

Exposures of this composition were made in midwinter and up to the end of the period when fouling was plentiful (312 days after immersion, in this case), the areas coated with this paint were, with the exception of traces of *Tubularia*, unfouled. This condition persisted throughout the winter until the spring settlement of barnacles. Inspection and assessment towards the end of April revealed a heavy, persistent settlement of this fouling organism and the composition was then rated as fouled. The maximum anti-fouling life of this composition is thus of the order of 470 days, but this is likely to be an over-estimate and failure probably occurred sometime during the winter. A more precise estimation of the anti-fouling life of this composition cannot be made on this exposure but, as *Tubularia* was known to be settling, in significant amounts, up to the end of December of the year in question, it is reasonable to suggest that 360-380

days is a minimum length for the anti-fouling life. With a composition of this type exposure should be made early in the summer, so that it can be subjected to a rigorous test early in the fouling season of the following year.

(d) *Composition with an Apparent Anti-Fouling Life.*

The fouling settling on any anti-fouling composition must be judged in comparison with that occurring on non-toxic surfaces, exposed over the same period and under the same conditions. It will be evident from the fouling sequence quoted in Table I. that the time of failure of a composition can be determined fairly accurately, if either :

(1) At the time when the composition ceases to offer adequate protection settling stages of resistant organisms such as *Tubularia* and *Enteromorpha* are available and the conditions of exposure are suitable for their settlement, or

(2) After falling below the critical value, the rate of loss of poisons falls low enough to allow settlement of moderately resistant forms such as *Ectocarpus*.

Should the rate of loss of poisons fall just below the critical value at a time when settling stages of resistant forms are not available, an estimation of the length of anti-fouling life may be misleading. The example given in Table VI. illustrates this possibility.

TABLE VI.—*Assessments of a Composition with an Apparent Anti-Fouling Life.*

Fouling Organism.	Mean Ratings after Exposure of (days) :		
	48.	85.	134.
Diatom	0.5	1.0	...
Tubularia . . . .	...	...	4.0
Fouling state	0	0	<i>f</i>

This example may be an instance in which the anti-fouling life was limited and thus where the assessments made give a true picture of the anti-fouling performance of the paint. On this basis the length of anti-fouling life could be estimated as of the order of 110 days. But the evidence from contemporaneous non-toxic exposures shows that, for the first part of the exposure period, *Ectocarpus* and *Obelia* were the chief fouling organisms available; *Tubularia* settlement did not begin until after the second assessment had been made. It is thus possible that the rate of loss of poison from this composition was only high enough to prevent settlement of *Ectocarpus* and *Obelia* and would not have been effective in preventing settlement of *Tubularia*. Had this composition been exposed at a time when the larvae of *Tubularia* were settling, its length of anti-fouling life may have proved to be negligible.

(e) *Example of Temporary Fouling.*

Occasionally an exposure may become fouled, but there is evidence that settlement is by no means secure, and there are no signs of further fouling. Under such circumstances it may be difficult to decide when the composition has ceased to give adequate protection. One of the most awkward cases of this state is given in Table VII.

TABLE VII.—*Assessments in a Case of Temporary Fouling.*

Fouling Organism.	Mean Ratings after Exposure of (days) :							
	30.	64.	89.	121.	152.	179.	208.	243.
Diatom . .	...	...	...	...	...	1.0	1.0	3.0
Ulothrix . .	...	...	...	...	...	0.5	4.0	2.0
Balanus . .	...	...	...	...	4.0	4.0	4.0	3.0
Fouling state .	0	0	0	0	? F	? F	? F	? F

An extensive settlement of barnacles occurred between the 121-day and 152-day inspections. This settlement has largely persisted, but the settled barnacles are very lightly attached and, though growth has occurred, they could readily be washed from the surface. The length of anti-fouling life for this composition could be estimated as 130–140 days, but, in view of the precarious nature of the barnacle settlement and the absence of other fouling, the fouled state of this exposure seems doubtful.

VI.—SUMMARY.

(1) The scheme of assessment used for the evaluation of the fouling which may settle on an anti-fouling composition should be of such a nature as to allow both for the varied sensitivities of the fouling organisms to the poisons which are being released from the paint and for variation in availability, due to restricted breeding periods, of the settling stages of these organisms. A scheme of assessment is described which attempts to allow for these factors, particularly for the first, which may be termed the sensitivity factor.

(2) The method of assessment used is briefly outlined. Exposed surfaces are examined, approximately at monthly intervals, under water in a shallow wooden trough. Each fouling organism that can be recognized separately under these conditions is rated separately, on a 0 to 7 geometrical scale. This scale is based on the numbers of each organism which have settled and not on their size or, in general, on the area which they have covered.

(3) The common fouling organisms occurring at Millport differ widely in their sensitivities to the poisons (copper and mercury) commonly used in anti-fouling compositions. This variation in sensitivity permits the compilation of what is termed a "fouling sequence." This sequence is described.

(4) It is emphasized that this fouling sequence is fundamentally a statement of an ideal case. Some of the more important complicating factors are discussed.

(5) Methods of analysis of assessment data are briefly discussed and a method of treatment described which has given satisfactory results. Essentially this method is a compromise; further work is necessary before a more precise method of treatment can be safely used.

(6) Examples are given of assessments made according to this scheme. These examples are briefly discussed and comments made on points of interest.

VII.—ACKNOWLEDGMENTS.

Though this paper appears under the name of a single author, many members of the research team working on the fouling problem have both helped in the evolution of this scheme of assessment and taken a very

considerable part in the labour of the assessments that have been made. Grateful acknowledgment is made to Professor J. E. Harris, under whose direction this work was carried out, and to whose interest and encouragement the development of this scheme is due; to Dr. M. F. Mare (Mrs. G. M. Spooner), who was largely responsible for the early development of the scheme of detailed assessments; to Miss J. C. Mott, who made a very considerable share of the assessments during the time she was a member of the research team; and to Mr. M. W. H. Bishop, who more recently has played an active part in making assessments of fouling according to the scheme set out in this paper.

Other work carried out by members of the research team has been freely used in preparing this paper. In this connection mention should be made of work on bacterial slimes carried out by Dr. M. F. Mare and particularly to Miss Stanbury's extensive survey of the sensitivities of plant fouling organisms.

REFERENCES.

Throughout this paper, no diagrams have been given of the organisms mentioned as commonly settling on exposed panels. Many of these are common marine organisms and adequate illustration is available in many of the books published on marine biology. A short list of such publications is given under (b) below.

(a) References Quoted in the Text.

1. FIRST REPORT OF THE MARINE CORROSION SUB-COMMITTEE: *Journal of The Iron and Steel Institute*, 1943, No. I., pp. 406-408 p.
2. S. A. WAKSMAN, D. B. JOHNSTONE, and C. L. CAREY: *Journal of Marine Research* (Sears Foundation), 1943, vol. 5, pp. 130-152.
3. *Journal of The Iron and Steel Institute*, 1943, No. I., p. 407 p.
4. *Ibid.*, p. 408 p (Fig. 10).
5. *Journal of The Iron and Steel Institute*, 1944, No. II., p. 146 p.

(b) References to Works on Marine Organisms.

The paper on "Fouling of Ships' Bottoms: Identification of Marine Growths" (reference 5 above) contains coloured plates, line diagrams, and photomicrographs of most of the organisms mentioned in the present paper. It also contains simple keys which may assist in the identification of unknown forms. For more detailed information the following works may be suggested:

(i) Marine Algae (Seaweeds).

- F. E. FRITSCH: "The Structure and Reproduction of the Algae." Vol. I. (including the Green Algae and Diatoms) 1935; Vol. II. (including the Brown and Red Algae) 1945. London: Cambridge University Press.
- W. H. HARVEY: "Phycologia Britannica," 4 vols. London, 1846-51: Reeve Bros.
- M. KNIGHT and M. W. PARKE: "Marx Algae: An Algal Survey of the South End of the Isle of Man," *Proceedings and Transactions of the Liverpool Biological Society*, 1931, vol. 45, Appendix II.
- L. NEWTON: "A Handbook of the British Seaweeds." London, 1931: British Museum Natural History.

(ii) Hydroids.

- T. HINCKS: "A History of the British Hydroid Zoophytes." 2 vols. London, 1868: John van Voorst.

(iii) Tube Worms (Annelids).

- P. FAUVEL: "Polychetes Sedentaires." Faune de France, Vol. 16. Paris, 1927: Paul Lechevalier.
- W. C. MCINTOSH: "A Monograph of the British Marine Annelids," Vol. IV., Part II. London, 1923: Ray Society.

(iv) Crustacea (Barnacles, Jassa).

- E. CHEVREUX and L. FAGE: "Amphipodes." Faune de France, Vol. 9. Paris, 1925: Paul Lechevalier.
- C. DARWIN: "A Monograph on the Sub-Class Cirripedia." London, 1854: Ray Society.

- H. A. PILSBRY : "The Sessile Barnacles (Cirripedia) contained in the Collections of the U.S. National Museum; including a Monograph of the American Species." Smithsonian Institution. United States National Museum. Bulletin No. 93, 1916.
- G. O. SARS : "An Account of the Crustacea of Norway." Vol. I. "Amphipoda." Oslo, 1895 : Alb. Cammermeyers.
- (v) *Mollusca* (*Mytilus*, *Anomia*, *Pecten*).
- E. FORBES and S. HANLEY : "A History of the British Mollusca." 4 vols. London, 1853 : John van Voorst.
- (vi) *Polyzoa*.
- T. HINCKS : "A History of the British Marine Polyzoa." 2 vols. London, 1880 : John van Voorst.
- (vii) *Tunicata* (Ascidians).
- J. ALDER and A. HANCOCK : "The British Tunicata." 3 vols. London, 1904, 1906, 1911 : Ray Society.

SOURCES OF ERROR IN DIAMOND PYRAMID HARDNESS MEASUREMENTS ON HARDENED STEEL.*

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(Figs. 3 to 7 = Plate XXIII.)

SYNOPSIS.

The purpose of this work was to determine the extent to which the results of diamond pyramid hardness (H_D) tests carried out by independent observers on hardened steel could be relied upon, experience having shown that some observers reported widely different results on material of the same nominal composition and heat-treatment. The conclusions apply generally to all hardness testing. As materials or components are sometimes accepted only to a given H_D specification, it is important that the H_D figures obtained should be reliable. Wide variation in the results reported by independent observers was found, although results within close limits of agreement were obtained on the same samples by an experienced observer, when care was taken in the preparation of the flats. The wide variations obtained are attributed to carelessly prepared flats, and a standardized procedure for surface preparation is therefore recommended.

DURING the course of research into methods of inspection, an automatic machine has been developed for the rapid (120/min.) hardness inspection of small steel components which are required to have a nominal diamond pyramid hardness number (H_D) of 850 for acceptance. For its operation the machine depends upon the magnetic properties of the steel, H_D being used as referee.

It is essentially a method suitable for the non-destructive testing of large quantities of mass-produced components of the same size and chemical composition. Each sample is hopper-fed into a magnetizing coil, where it is magnetized to saturation. The retentivity is measured by means of a search coil situated at the centre of a solenoid, the field of which is opposed to that of the original magnetization. The current in this solenoid is the "machine setting," and the milliammeter scale may be used as an arbitrary magnetic hardness scale. The method is to grade a large representative sample (say, 1000 test-pieces) by the machine into hardness groups, each group decreasing by two magnetic hardness units. From these groups a few (say, 5) samples are selected and H_D determined on each. A correlation can thus be obtained between magnetic hardness (*i.e.*, machine setting) and H_D . The machine setting is observed for the corresponding acceptance figure of H_D , and this setting is used to test the bulk of the factory production by the magnetic hardness testing machine. For the application of this method it is important that independent observers should obtain the same H_D results within close limits on identical specimens. Preliminary work showed that this was not the case, and accordingly an investigation was undertaken to examine the capabilities of various observers.

* Received May 5, 1945.

PREPARATION AND SELECTION OF THE TEST SPECIMENS.

Two chromium-molybdenum steel rods, approximately $\frac{1}{4}$ in. in dia. and of the same nominal composition (carbon 1.0, manganese 0.6, chromium 2.0, molybdenum 0.3%), were provided and identified as batch *A* and batch *B*. Batch *A* was reputed to harden better than batch *B*. From each of these batches specimens were cut and identified by their batch letter and a number. Both batches were oil-quenched from 850° C.

For the purpose of this investigation it was desirable that specimens of both high and somewhat lower hardness should be included. The specimens from batch *B* were therefore tempered. As the specimens were to be selected from a narrow range of hardness, as determined by magnetic hardness grading, they were all cut to identical lengths.

Table I. shows the number of specimens corresponding to each figure on the arbitrary magnetic hardness scale.

TABLE I.—*Number of Specimens at Each Magnetic Hardness Value.*

Batch.	Magnetic Hardness Scale.														
	101.	100.	99.	98.	97.	96.	95.	94.	93.	92.	91.	90.	89.	88.	87.
<i>A</i>	12	52	23	2	...	...	...	...	...	...	...	...	...	...	...
<i>B</i> . . . . .	...	...	2	2	10	7	17	12	13	7	0	1	...	...	...
<i>B</i> (tempered) . . .	...	...	...	...	...	...	...	...	...	9	26	20	8	7	1

The specimens for the various observers were selected from the following groups :

A.
12 at 101 magnetic hardness, and
52 at 100 magnetic hardness.

B.
26 at 91 magnetic hardness,
20 at 90 magnetic hardness,
8 at 89 magnetic hardness, and
7 at 88 magnetic hardness.

By convention "12 samples at 101 magnetic hardness," for example, indicates that these samples were within the range 101 to 102 magnetic hardness (theoretically 101 to 101.9). Thus all the *A* samples are within the range 101 ± 1 , and all the *B* samples within the range 90 ± 2 magnetic hardness.

A list of the observers was drawn up and each one was allotted a number by which he could be identified. Each observer was provided with 2 samples of batch *A* and 2 samples of batch *B*, and was asked to make three H_D impressions on each sample, viz.: one near each end and one approximately in the middle. The samples, together with each observer's results, were in due course returned.

The results received were carefully studied. They were tabulated and plotted in Fig. 1 (*a*) for the *A* series, and Fig. 2 (*a*) for the *B* series. Next the observers' impressions were remeasured. Where the observer made several impressions on one sample, all the impressions were remeasured, the ocular readings and values of H_D being tabulated. Finally, new flats were ground on all the samples on the side opposite to the observers' flats, and H_D impressions made on the new flats by one observer. The ocular readings and values of H_D were tabulated and plotted in Fig. 1 (*b*) for the *A* series and in Fig. 2 (*b*) for the *B* series.

Fig. 1 gives a direct comparison of the independent observers' H_D figures with the H_D figures determined on all samples by one observer.

Fig. 2 gives a similar comparison. From a study of the individual results and the collective results in Figs. 1 and 2, conclusions have been drawn which will be considered separately.

The general conclusion is that there is considerable variation in the submitted H_D readings, the main causes being :

- (1) Insufficient care in the preparation of the flat.
- (2) The use of a cracked or chipped diamond.
- (3) Incorrect mounting of the specimen.

A discussion of the observers' results taken collectively is considered under four headings, *viz.* : (1) Abnormally high readings, (2) abnormally low readings, (3) readings with a wide range, and (4) other readings.

DISCUSSION OF THE OBSERVERS' RESULTS.

(1) *Abnormally High Readings.*

A few observers, notably Nos. 15 and 19 for the *A* samples and Nos. 17, 19, and 20 for the *B* samples, obtained high readings for one or both of their samples. Of these Nos. 19 and 20 used damaged diamonds, although their flats were classed as "Good." This fact may partly account for their high readings, the fracture being of such a character as to offer greater resistance to penetration and thus giving a smaller impression and a higher value of H_D . On remeasuring these observers' impressions, however, it appeared that an error in setting the ocular knife-edges had been made, which would account partly for the high readings submitted.

The flats made by observers Nos. 15 and 17 were classed as "Not good" and "Fair," respectively, and this probably accounts for the high readings obtained (which might with somewhat less or equal probability have been abnormally low), the precise setting of the knife-edges being made quite impossible by the badly defined corners of the impression.

(2) *Abnormally Low Readings.*

Figs. 1 and 2 indicate that there is a greater tendency among observers in general to obtain abnormally low than abnormally high readings. This is most probably due to the susceptibility of the hardened steel to local tempering during the grinding of the flat. In none of the more obvious cases (observers Nos. 8, 12, 15, 16, 21, 21A, 24, and 25 with *A* samples, and observers Nos. 8, 12, 16, 21, 21A, 24, and 25 with *B* samples) did the local tempering seriously affect the new flats which were ground parallel to the original flats on the opposite side of the specimen. Some of the less obvious cases of low readings (observer No. 18 with *A* samples, observers Nos. 18 and 18L with *B* samples) are probably due to the fact that their flats were classed as "Not good," with consequent difficulty in making a precise setting of the knife-edge. It would require a very skilled operator to judge the correct setting if, for instance, one corner of the impression coincided with a scratch which showed up as a dark line and masked the corner of the impression.

(3) *Readings with a Wide Range.*

Readings showing a wide variation in values of H_D on a given sample may be attributed to one of the following causes or combinations of them :

(a) Local tempering of the flats during preparation, the amount of tempering probably varying along the sample (*e.g.*, Fig. 1 (a), observers Nos. 8 and 24; Fig. 2 (a), observers Nos. 8, 24, and 25).

(b) Lack of discrimination in setting the ocular knife-edges due



FIG. 1.—Results of Diamond Pyramid Hardness Tests on chromium-molybdenum steel rods oil-quenched from 850° C. (batch A), obtained (a) by various observers and (b) by observer No. 28 on new flats ground on the specimens of all the other observers.

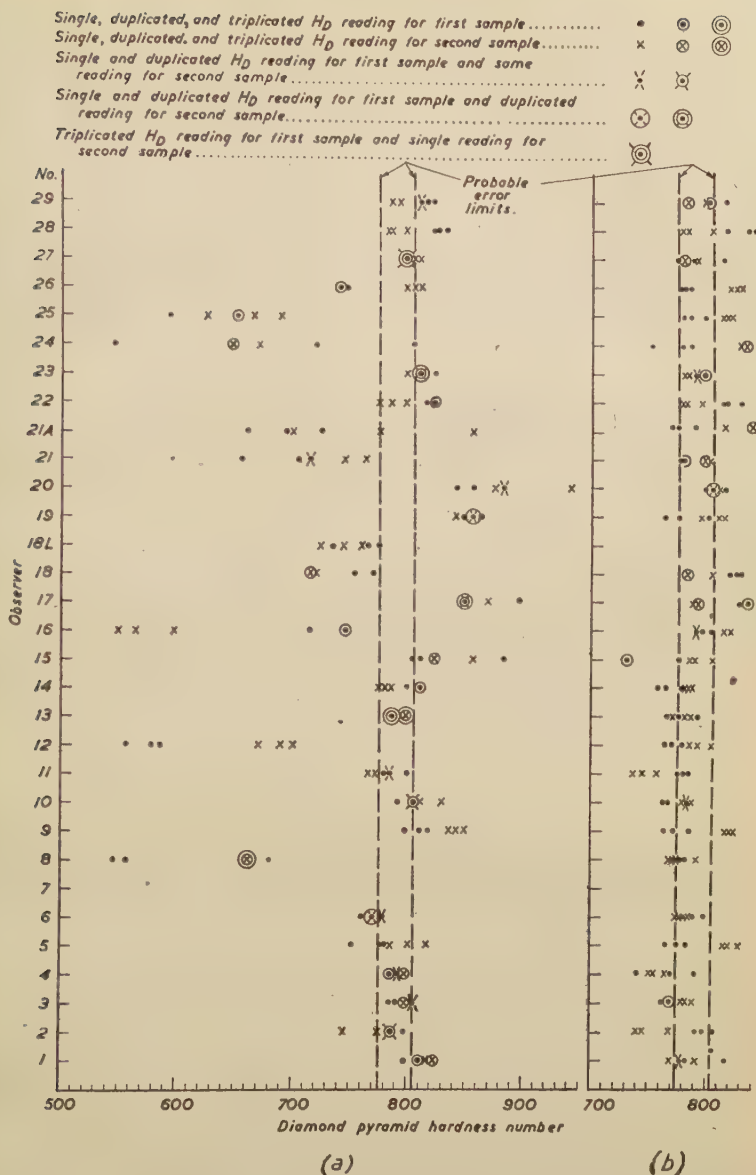


FIG. 2.—Results of Diamond Pyramid Hardness Tests on chromium-molybdenum steel rods oil-quenched from 850° C. and tempered (batch B), obtained (a) by various observers and (b) by observer No. 28 on new flats ground on the specimens of all the other observers.

to the bad finish of the flat (*e.g.*, Fig. 1 (a), observers Nos. 14 and 21A; Fig. 2 (a), observer No. 15).

(c) Too great a difference between the two diagonal readings for one impression, owing to (i) bad finish of the flat, (ii) curvature of the "flat," or (iii) insufficient care in mounting the samples so that the travel of the diamond is not normal to the flat (*e.g.*, Fig. 1(a), observers Nos. 20 and 21A; Fig. 2(a), observer No. 21A).

(4) Other Readings.

Where the results obtained have been in good agreement with those of observer No. 28 on the same sample, but where the preparation of the flat was bad or the impressions were irregularly shaped, it is considered that the various errors have counteracted each other to some extent and that it is only by chance that the first results have been good (*e.g.*, observers Nos. 6 and 14).

PHOTOMICROGRAPHS.

A selection of five photomicrographs taken from observers' submitted H_D impressions is shown in Figs. 3 to 7.

Fig. 3 shows a typical impression taken at random. The impression has sharp edges, sharp corners, and equal diagonals. The surface of the sample shows the minimum permissible polish required to obtain a good impression.

Fig. 4 shows a badly polished surface. The scratch lines of the polish mask the corners of the impression so that the diagonals cannot be measured with any accuracy.

Fig. 5 also shows a badly polished surface, and in this case the travel of the diamond was not normal to the flat, giving a kite-shaped impression.

Fig. 6 shows not only a kite-shaped impression, but also the effect of a tipless diamond. A portion of the original surface with scratch lines can be seen inside the impression.

Fig. 7 shows the effect of a chipped diamond. A small indentation is seen near the top corner of the impression (top right-hand edge).

ASSESSMENT OF ERRORS.

As all the diamond indenters used by the observers were obtained from the same source, *viz.*, Messrs. Vickers-Armstrong, Ltd., the possibility of effects arising from variations in the 136° indenters¹ has been ruled out. It is, however, of interest to note that the effects of such variations have been investigated elsewhere,² and the results indicate that "discrepancies in hardness data and non-geometrically shaped impressions may be expected for properly calibrated and operated H_D machines unless the accuracy and workmanship of the diamond pyramid indenters are satisfactorily controlled."

An attempt was made to distinguish and assess errors of the following types :

- (a) Error in setting the microscope ocular knife-edges, including the departure of individual microscopes from their rated magnification.
- (b) Overall probable error for one observer using one machine.

(a) *Microscope Errors—Personal and Instrumental.*—If a number of reasonably skilled observers measure one well-defined impression with the same microscope, agreement to within a probable error of ± 1 ocular unit for diagonals of approximately 250 ocular units may be expected. In the present investigation a study was made of the differences between individual observer's submitted readings and the readings obtained by remeasure-

ment of the impressions by observer No. 28. The various observers were asked to submit three readings for each sample, but in many cases several other impressions were made. These were all remeasured by observer No. 28, and the nearest one to the corresponding submitted reading was taken in calculating the above differences.

It will be appreciated that this test also involves differences in microscope magnification between a given observer's machine and observer No. 28's machine. For a $\frac{2}{3}$ -in. objective every microscope is adjusted by the makers to a nominal magnification such that 1 ocular division = 0.001 mm. To check this variation in microscope magnification, another machine was made available to observer No. 28, and the results for hard and soft test blocks are given in Table II. It will be seen that for the hard test block the difference in magnification is likely to lead to an error of approximately 22 H_D units, corresponding to 3 ocular divisions at approximately 920 H_D . The difference is negligible for the soft test block using the same load.

Thus, in many cases the significance of the difference between the observers' submitted readings and the remeasured readings may be masked entirely by differences in microscope magnification, and no assessment of the setting error is thus possible in the present investigation.

TABLE II.— H_D Measurements Taken on Hard and Soft Test Blocks by Different Vickers Machines.

The impressions made by one machine (*A*) were measured first with the microscope belonging to that machine, and secondly with the microscope belonging to the other machine (*B*). A load of 30 kg. was used in each case.

	Measured on Machine.	Ocular Readings.	H_D .
<i>Hard Test Block :</i>			
Impression No. 1 made by machine <i>A</i>	{ <i>A</i> .	247/8, 246/7	912
	{ <i>B</i> .	243, 245	934
Impression No. 2 made by machine <i>B</i>	{ <i>B</i> .	244, 244	934
	{ <i>A</i> .	247, 246/7	912
<i>Soft Test Block :</i>			
Impression No. 1 made by machine <i>A</i>	{ <i>A</i> .	484, 480	240
	{ <i>B</i> .	481, 477	243
Impression No. 2 made by machine <i>B</i>	{ <i>B</i> .	476, 480	244
	{ <i>A</i> .	476, 483	242

(b) *Probable Error for One Observer Using One Machine.*—A standard of comparison is necessary by which to judge the relative merit of each observer's readings. In this investigation observer No. 28 ground and polished new flats by a method which had proved in practice to give most reliable results (*see below*). New impressions were made to correspond with each observer's impressions.

As the samples were selected from a narrow range of magnetic hardness, the overall probable error—obtained by statistically combining the results of each of the series *A* and *B*—was considered the best basis for comparison.

It should be emphasized that the magnetic hardness values are relative only, and mutually comparable only for the samples in the present investigation. Magnetic hardness values are strictly intercomparable only for samples of the same size and shape, from the same melt of steel, and heat-treated under identical conditions. They may be intercom-

parable for different samples of steels over a limited range of composition and heat-treatment, other factors being constant.

Table III. shows the results of the statistical survey of all measurements by observer No. 28.

TABLE III.—*Results of Statistical Survey of Measurements Taken by Observer No. 28.*

58 Samples from Series A.		58 Samples from Series B.	
Magnetic Hardness Range.	Average H_D and Probable Error Limits.	Magnetic Hardness Range.	Average H_D and Probable Error Limits.
101 \pm 1	870 \pm 7.5	90 \pm 2	790 \pm 15

The limits of probable error are shown in Figs. 1 (b) and 2 (b) and redrawn in Figs. 1 (a) and 2 (a) respectively.

SUMMARY OF SOURCES OF ERROR.

The sources of errors in H_D measurement procedure may be summarized as follows :

(1) *Preparation of the Flat.*

(a) Local tempering, causing (i) low readings in general, and (ii) wide variation of readings on one specimen.

(b) Residual curvature of the "flat," causing kite-shaped impressions, the mean of the diagonals being unreliable.

(c) Lack of final polish, causing the corners of the impressions to be badly defined, with consequent inaccuracy in setting the ocular knife-edges.

(2) *Mounting the Sample.*

(a) Lack of normality of the travel of the diamond to the flat, causing (i) irregular or kite-shaped impressions, and (ii) lateral strain on the diamond.

(b) Lack of rigidity in supporting the specimen, causing (i) irregular or kite-shaped impressions, and (ii) lateral strain on the diamond and consequent tendency to fracture.

(3) *Microscope Errors.*

(a) The difference between the actual magnification and the rated magnification.

(b) Measurement of the impression—systematic and accidental errors :

(i) Tendency to set the ocular knife-edges too near, causing high H_D results.

(ii) Tendency to set the ocular knife-edges too far apart, causing low H_D results.

(iii) Faulty zero adjustment, causing systematic high or low H_D results.

(iv) Probable error for any given observer using any given machine.

On the preparation of the surface of the specimen depends for the most part the accuracy and consistency of the H_D impressions made by the machine. Any discrepancies still persisting can then be traced either to the observer in the measurement of the diagonals of the impression, or

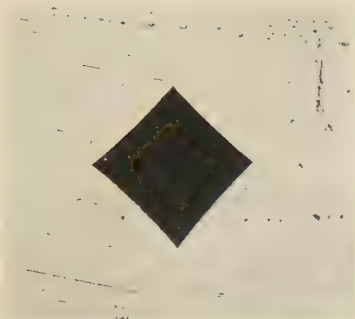


FIG. 3.—Typical Impression, with sharp edges, sharp corners, and equal diagonals.

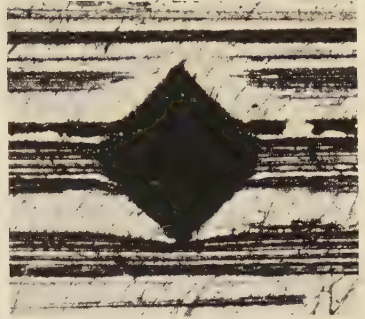


FIG. 4.—Scratch Lines Masking the Corners.

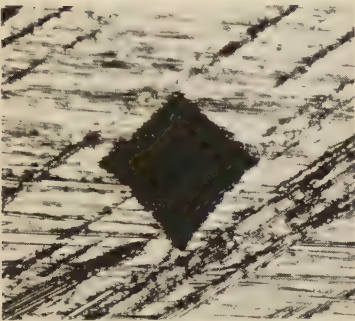


FIG. 5.—Travel of Diamond Not Normal.

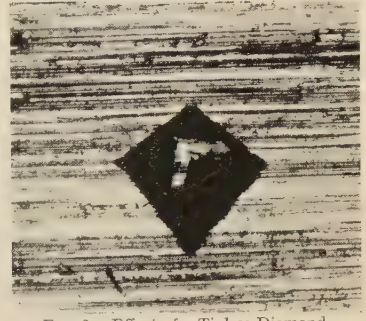


FIG. 6.—Effect of a Tipless Diamond.

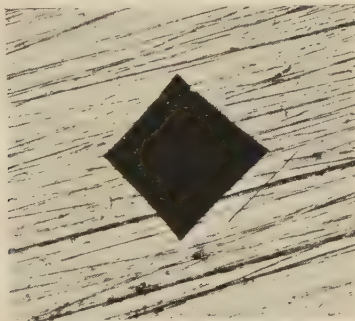


FIG. 7.—Effect of a Chipped Diamond.

FIGS. 3 to 7.—Diamond Pyramid Hardness Impressions. $\times 100$.

(Illustrations reduced to four-fifths linear in reproduction.)

[Hindley.
[To face p. 252 P.

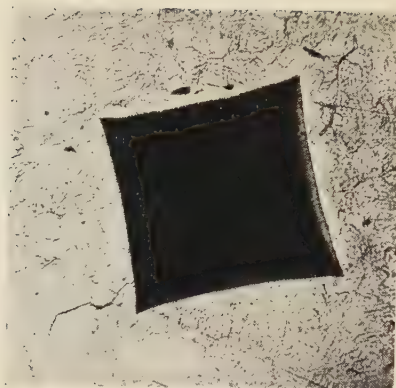


FIG. A.—0.89% Carbon Steel quenched from 930° C. $\times 175$.

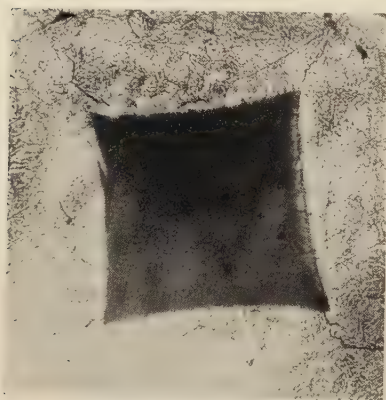


FIG. B.—1.20% Carbon Steel quenched from 930° C. $\times 175$.

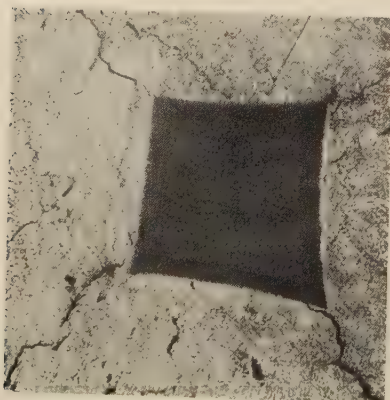


FIG. C.—1.20% Carbon Steel quenched from 930° C. and immersed in liquid nitrogen for 1 hr. $\times 175$.

(See Wrażej's contribution.)

[Discussion on Hindley,
[To face p. 253 p.

to the machine in making the impression. The variations arising from the last-named sources should be comparatively small.

H_D impressions are sometimes made on cylindrical surfaces of small diameter. This procedure, in which the diagonal of the impression parallel to the axis of the rod only is measured, can be regarded as giving only a rough idea of the true hardness. It is clear that the load on the corners at the ends of the longer diagonal (*i.e.*, parallel to the cylinder axis) is greater, and that on the other corners less, than the equally distributed load on all corners when testing on a flat. In consequence, the axis diagonal may be too long, whilst the transverse diagonal is definitely too short, and measurement of it introduces an error; no reliability can therefore be attached to such readings. A further discrepancy may be introduced by a decarburized surface.

RECOMMENDED PROCEDURE FOR SURFACE PREPARATION.

Whilst there is nothing new or unique about the procedure given here, it is important that a standardized procedure should be adopted, so that the H_D figures of independent observers may be comparable and reliable.

The procedure given has been used essentially for rods, but may be suitably amended for other shapes. The rod is clamped horizontally in a vice and a carborundum file used with long slow strokes evenly applied with light hand pressure to obtain a flat approximately 0.1 in. wide. The use of a carborundum wheel, even with the specimen immersed in water, is to be deprecated, as local tempering is likely with very hard steels. The specimen is transferred to a jig which consists simply of a clamping block attached to an arm that is made to travel by hand over a board on which are clamped at one edge sheets of emery paper, *e.g.*, Oakey's *F* (uppermost), *FF*, Naylor's *1M*, 0, 00. At each successive change of emery paper, the clamping block is turned through a right angle, and polishing continued on one particular paper until all the marks of the preceding paper have been removed. In this manner a good flat is obtained. In the case of $\frac{1}{4}$ -in. dia. bar, the flat is approximately $\frac{1}{8}$ in. wide and corresponds along its centre line to a depth of approximately 0.010 in. below the original surface. The clamping block complete with sample may then be inverted and stood on the table of the Vickers machine for hardness measurement.

In the actual measurement of the diamond indentation by the micrometer eye-piece, it is usual for the different observers to agree on the setting of the knife-edge to within ± 1 ocular unit (± 0.001 mm. for a $\frac{2}{3}$ -in. objective). This difference in ocular reading varies in significance at different positions of the hardness scale, since the length of the diagonal of an impression made on very hard material, such as tungsten carbide, is only about a quarter of that of an impression made on mild steel with the same load and objective. For a range of 850–950 H_D it is estimated that the overall accuracy in the measurement of a diagonal is approximately ± 1.5 ocular units. The difference between the measured values of the two diagonals of the same indentation depends largely on the condition of the surface of the flat and its normality to the travel of the diamond. The two diagonals may differ by as much as 4 ocular units; but if the difference is greater than this, a new impression should be made. The average of the two diagonals is taken and the value of H_D read from the table for the load used—usually 30 kg. for materials in the range 850–950 H_D . A difference of 1 ocular unit is equivalent to 8 H_D units in the region of 950 H_D , so that any results in this region may have a probable error of approximately ± 10 to ± 15 H_D units.

ACKNOWLEDGMENTS.

Thanks are due to Mr. F. Drury for the many hardness measurements which this investigation entailed, and to the Director General of Scientific Research and Development, Ministry of Supply, for permission to publish the results of this investigation.

REFERENCES.

1. R. L. SMITH and G. E. SANDLAND: *Journal of The Iron and Steel Institute*, 1925, No. I., p. 285.
2. F. B. FULLER: *Transactions of the American Society for Metals*, 1937, vol. 25, pp. 1198-1206.

DISCUSSION.

(Figs. A to C = Plate XXIII.A.)

In the absence of the author owing to illness, the paper was presented by Dr. R. H. GREAVES (Research Department, Woolwich).

Dr. W. STEVEN (Messrs. William Jessop & Sons, Ltd., Sheffield): Diamond hardness measurement is so much a part of our daily routine that the discrepancies between different observers brought to light by Dr. Hindley's survey must be regarded as yet another example of familiarity breeding contempt, the contempt in this instance taking the form of carelessness. If the scatter shown in Figs. 1(a) and 2(a) really is representative—and I should like to ask the author to indicate just how representative he considers that it really is—then this paper is timely, if not overdue.

Dr. Hindley has covered the majority of the possible sources of error, but I feel he has not sufficiently stressed their relative importance. He quite rightly emphasizes the importance of good surface finish, of careful mounting, and of using an indenter in good condition, but on examination his data indicate that the errors derived from these three sources are of a distinctly lower order than those due to local tempering during preparation.

There are two other possible sources of error which might have been more heavily stressed. The first of these is faulty zero adjustment and is mentioned on p. 252 P. It is extremely easy, by winding the knife edges together too tightly, to introduce a serious zero error, and as a source of error in day-to-day testing this probably ranks high in order of probability. The second is that caused by winding the diamond into the specimen during the preliminary adjustment of the level of the specimen before applying the load, a mistake frequently made by inexperienced operators. Both of these sources are capable, at least potentially, of developing errors greater than those ascribed to surface finish, mounting, and damaged indenter.

One of the sources of error which attracted my attention was that due to a difference between the rated and actual magnifications of the microscope. Is Dr. Hindley yet in a position to say whether the figure of 3 ocular points mentioned represents an average or an extreme case?

In Figs. 1(b) and 2(b) the author has included a probable error range. The derivation of this is not altogether clear from the text, and I may have interpreted the origin incorrectly, but I have formed the opinion that a comparison of the observations plotted in Figs. 1(b) and 2(b) with this

range represents an assessment of the accuracy with which surface hardness can be measured by the magnetic apparatus, rather than an assessment of the probable error of a single observer.

Finally, I should like to thank the author for a most interesting paper. In particular I found the straightforward and practical approach to the problem most refreshing. If the author has the opportunity I should like to recommend that he extends this work to cover Rockwell hardness testing. A clear exposition of the errors in hardness testing would be of considerable value.

Dr. W. J. WRAŻEJ (Imperial College of Science and Technology, London): Although the factors which cause irregularity in the measurement of diamond hardness are well recognized, the author has rendered a most useful service in summarizing them, and the procedure which he recommends for the preparation of the surface on the penultimate page of the paper should prove of considerable practical value. It is evident that mechanical means for the preparation of the surface should be avoided, as they tend to produce alteration in the structure of the steel. The author has made some observations on this point, and I should like to contribute a few remarks, based on some work which I have described in a recent paper.*

There is another source of error in the determination of diamond-hardness values, both in plain carbon steels and in nickel-chromium steels. Some samples containing 0.75%, 0.89%, and 1.20% of carbon, and nickel-chromium steels containing 0.3% of carbon, 3.9% of nickel, and 0.6% of chromium were quenched in brine after being heated to various temperatures *in vacuo*. Before testing the hardness with our Firth hardometer, the specimens were polished and etched to reveal the structure. Great variations in hardness values were observed, although the structures at the points selected for each test were nearly the same in each individual sample. These points were chosen with the aid of a microscope.

Careful examination of the impressions showed that in the case of those with lower hardness numbers there was the appearance of intergranular cracks in the martensite (Figs. A and B), and the larger the grains of martensite the more visible were the cracks. It must be emphasized that the cracks always appeared at the examined surface, though sometimes after a short delay of about a minute or less. The cracks were always intergranular, and they were not connected with the splitting of a grain by the edge of the diamond (Figs. A and B). The nature of the cracks has been studied in relation to the complete absence of plasticity in martensitic steels, and a detailed description will be given in the reports.

It is easy to visualize the growth of such cracks, produced during the hardness testing of untempered steel, into the microcracks which form so readily in quenched steels, for instance tools and small parts. Microcracks are produced also by immersing quenched steels in liquefied gases—nitrogen or air—and such treatment renders the steel more sensitive under the indentation and will make it crack more readily (Fig. C).

Tempering, on the other hand, even at 100° C., prevents cracking, and, although it changes martensite into the first stage of troostite, it does not render the steel suitable for any deformation involving extension. It would appear that many other problems connected with the unsuccessful production of small parts require investigation. The author is to be congratulated on having demonstrated so convincingly these fundamental errors in the determination of hardness values.

* "Local Heating in Plain Carbon Steels," *Journal of The Iron and Steel Institute*, 1945, No. II., p. 189 F (this volume).

Dr. R. H. GREAVES (replying in the author's absence): Dr. Steven asked whether the observers responsible for the scatter shown in Figs. 1 and 2 could be regarded as representative. Obviously they are not representative of a good class of observer, but the extension of the use of the Vickers machine during the last few years has brought in a number of inexperienced people, and I think that they may be regarded as representative of a good cross-section of the observers actually using the machine for the purpose in question.

Several additional sources of error have been pointed out. I was interested to hear of Dr. Wrażej's experience of cracks affecting the accuracy of impressions in water-quenched steels. I do not think that the sections referred to in the paper were affected by cracking, because the steel had received a very slight tempering, which was probably enough to dispose of that class of error.

I will leave the author to deal with the other points in writing.

CORRESPONDENCE.

Mr. G. BURNS (Admiralty Engineering Laboratory, West Drayton) wrote: Dr. Hindley's paper forms a very useful summary of the points to which attention must be given if accurate results are to be obtained in diamond pyramid hardness testing.

The finding that there is a greater tendency for observers to return readings too low rather than too high is interesting, and seems worthy of rather more attention. Dr. Hindley assumes that this is due to local tempering of the specimen by improper preparation, but it does not appear in the paper that this point was definitely confirmed by having his "standard" observer make additional impressions on surfaces prepared by those observers who returned notably low results; the size of impression obtained by the various observers was checked, and this appears to have been taken as a sufficient indication that the material had indeed been locally softened.

Some time ago the writer noted a tendency for one or two observers to return a percentage of low results on material known to be very consistent in hardness and which, being nearly fully tempered, could not be regarded as susceptible to local softening by improper preparation. Observation indicated that, when working on small surfaces, it is possible for an observer to bring the diamond point into actual contact with the specimen and to make a very small impression without being aware of having done so; the reflected light from a well prepared surface may make the precise location of the diamond point difficult to observe from some angles, and the hand-wheel and screw give sufficient mechanical advantage to make contact difficult to perceive by touch. The result of making a small initial impression before applying the normal test-load is, of course, to obtain too large an impression and too low a result.

AUTHOR'S REPLY.

Dr. HINDLEY wrote in reply: Dr. Steven's comment on the extent to which the results may be representative has been dealt with by Dr. Greaves.

In the Summary of Sources of Error local tempering is mentioned as the first cause under the heading Preparation of the Flat. It is true that local

tempering has a greater effect on H_D errors than the three main causes cited on p. 247P. Having given detailed procedure for the preparation of the flats local tempering should be eliminated, whilst errors in technique may still persist.

Checking the zero adjustment is undoubtedly important. It is expected, however, that machine operators should be familiar with the instruction booklet supplied by Messrs. Vickers Armstrong, Ltd., with the machine, and that those in authority should see that machine operators have easy access to that booklet.

The winding of the diamond into the specimen can only be regarded as more than ordinary carelessness. It does occur with beginners, and occasionally with regular users, as indicated by tipless diamonds.

These points seem to emphasise the need for the employment of a better class of operator on hardness measurement. The Vickers hardness machine can be classed as a precision instrument. Experience seems to indicate that operators who use the machine many times a day acquire a technique, and consequently produce more accurate results than those who use the machine only once or twice each day. Where several operators use the same machine, experience shows that none takes the responsibility of seeing that the machine is in correct adjustment. An obvious point is that the hardness machine must be suitably sited. A case was reported to me of a Vickers hardness machine standing next to a chromium-plating equipment, with consequent severe corrosion of the former.

Information is not available to adjudge whether the 3-ocular-units error represents an average or an extreme case. This would have necessitated sending the "standard" observer to the works and laboratories of the 30 observers to measure, by their microscopes, impressions made by the "standard" machine on a given test-piece. This would have increased considerably the already heavy labour. I might add here a testimony to the patience of my standard observer.

The probable-error limits were determined statistically. Omission of this determination has caused a misapprehension. The H_D results do not represent an assessment of the accuracy with which surface hardness can be measured by the magnetic apparatus. The H_D figures are used as references for setting the magnetic apparatus for accepting or rejecting samples on either side of a given H_D figure. The importance of the accurate determination of H_D is therefore emphasised. It is hoped that permission may be obtained to publish a paper on magnetic hardness in which the method to which reference was made in the second paragraph of the paper will be given in detail, together with a description of its use as a system of quality control.

Reverting to the determination of the probable-error (P.E.) limits, the standard deviation, σ , is first determined; then $P.E./\sigma = 0.6745$ in the Gaussian distribution.

The standard deviation of a set of numbers $X_1, X_2, X_3, \dots, X_n$ is the square root of the average of the squares of the deviations of the numbers from the average \bar{X} . This is σ or the root mean square (R.M.S.). $R.M.S. \times 0.6745 = P.E.$ This figure is added to and subtracted from the arithmetic mean of the numbers to obtain the P.E. limits.

I appreciate the suggestion that this survey might be extended to cover Rockwell hardness testing. The prospect of my being able to do this is very remote. I mention this as other workers in this field may wish to carry out a similar investigation.

Dr. Wrażej's reference to microcracks is particularly interesting, as I have observed cracks similar to those shown in Figs. A to C on untempered specimens. The cracks radiated from the corners of the H_D impression, but were observed in only one batch of steel of similar composition to that used in this investigation.

With reference to Mr. Burns' correspondence, it is confirmed for a small percentage of specimens that the "standard" observer's results agreed closely with other observers' results taken on the observers' flats. This was not done throughout the series, as it would have been difficult to differentiate between the set of impressions made by the first observer and that made by the standard observer.

The difficulty noted by Mr. Burns can be overcome if a slip of paper is placed on the prepared surface while the specimen is brought up to the diamond and then removed before the impression is made.

In conclusion, I should like to thank Members for their interest in this paper and Dr. Greaves for its presentation in my unavoidable absence.

THE DISTRIBUTION OF MATERIALS IN THE BLAST FURNACE.—PART I.*

By H. L. SAUNDERS, PH.D., F.R.I.C., AND R. WILD, PH.D. (IMPERIAL
COLLEGE, SOUTH KENSINGTON).

(Figs. 38 to 133 — Plates XXIV. to XXIX.)

SYNOPSIS.

The distribution of materials in the blast furnace has been studied by the aid of small-scale models, using materials of correspondingly small size. The nature and extent of segregation depend upon the character of the materials, *e.g.*, variation in size, shape, density, and moisture content, considered in relation to the furnace lines, bell and throat design, &c. Such variables are treated first singly and then in groups, the distribution patterns obtained being followed photographically. The form of the stockline contour, which can be deduced from a knowledge of the trajectories, largely determines the initial distribution, which generally persists throughout the furnace shaft. Some examples of burden flow with spherical material are considered. Many illustrations are shown of simple and complex segregations, which are compared according to their origins, together with simple examples of compensation.

I.—INTRODUCTION.

THE extent of the chemical changes which occur in the various regions of the blast furnace depends upon the time of contact between the gases and the solids. It will be appreciated that neither the ascending gases nor the descending burden can normally move at a uniform rate at all points between the stockline and hearth, for not only does the diameter of the stack vary from one level to another, but the wide differences in the size of the materials constituting the burden introduce segregation, and therefore packing and voids will be very irregular. The blast will flow most readily through those regions where the materials are largest and the gas resistance is lowest. This unequal movement of gas and solids means that contact times vary from place to place as well as with time at any specified position; hence the extent of oxygen removal also changes in like manner.

Chemical change is also governed by temperature; this in turn depends on the rate of heat transfer between the hot reducing gases produced at the tuyeres and the cold material charged at the top. The contours of the isothermals will be determined not so much by the reactions themselves as by the selective channelling of the blast through the burden; the temperature gradients thus created impose limiting conditions upon the location of the regions for the various chemical reactions taking place. Even when a furnace is working well, reduction efficiency both locally and generally may be easily impaired by any new condition, *e.g.*, slip, upsetting the relationship obtaining between the rate of descent of the ore and its corresponding rise in temperature; for unless the isothermals happen to be horizontal the temperature increment encountered over a given vertical distance will be much greater in some cases than in others. Indeed it must often happen that some portions of the burden ultimately reach a high-temperature zone with insufficient preparation and consequently interfere with the proper functioning of the hearth. Whether we are concerned with the contours of the isothermals, the lines of similar gas composition, the optimum zones of carbon deposition, slag formation, or fusion of metal,

* Received March 16, 1945.

it may be stated without doubt that until we have a clearer insight into the mechanism of solid distribution, our knowledge of the conditions appertaining to maximum efficiency in any of the processes taking place within the blast furnace can never be complete.

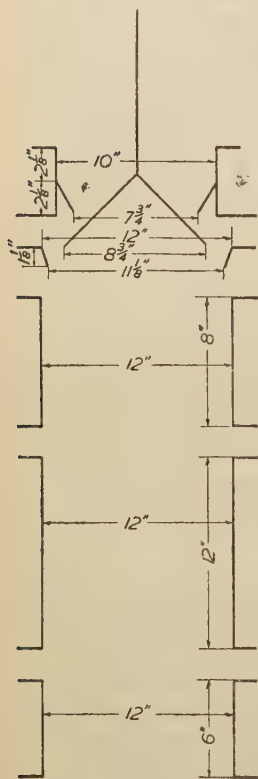
Distribution is indeed a problem covering a far wider field than blast-furnace technology, and even in iron-making it is not confined to the blast furnace alone. Similar problems arise in : (a) the storage of raw materials ; (b) the fuel beds of producer and gas machines ; (c) lime burning ; and (d) the preparation of sintering beds.*

The Use of Models.

How then can such problems be best investigated ? Field tests at Frodingham † disclosed a definite relationship between the shape of the isothermals, the $iso-CO_2$ lines, and the contour of the stockline. This can only mean that stockline segregation must play a very important part in furnace operation, and this fact was partly confirmed during subsequent tests on another furnace at Skinningrove. It would, however, have been quite impracticable to study all the different possibilities connected with distribution from full-scale practice, so attention was directed to the use of models. In such technique it is important to observe certain characteristics to ensure similarity (see Appendix). It is most important to use the correct size of materials in relation to the size of the model. In the work carried out at the Imperial College, South Kensington, several different scales were employed, varying from $\frac{1}{80}$ th to $\frac{1}{16}$ th (linear). At a later stage excellent confirmation of the laboratory results was obtained when a pilot blast furnace was erected at the works of the Shelton Iron, Steel and Coal Company, and a critical series of experiments was repeated on this new and much larger scale. This unit was subsequently put on blast and operated over a period of three months, making about half a ton of iron per day. ‡ Further details will be communicated in due course. In the small models certain modifications in cross-section were introduced for special reasons, but, except where otherwise stated, experiments were conducted at room temperature and also, in Part I. of this paper, without counter-current blast.

It was first of all necessary to make a preliminary survey to ascertain the nature of the factors that are responsible for, or have a direct bearing upon, variations in distribution, and then to study specific influences first singly and afterwards in groups of increasing complexity, making the maximum use of pictorial records.

FIG. 1.—Vertical Section through Model 1 (large-scale shaft model).



* Items (b) and (c) have been studied in some detail and will form the subject of a separate paper.

† The Iron and Steel Institute, 1937, *Special Report No. 18*.

‡ G. H. Goodwin, *Iron and Steel*, 1945, vol. 18, pp. 6, 17. (Preliminary note.)

The preliminary experiments were carried out in Model 1 (Fig. 1). This consisted essentially of a series of galvanized sheet cylinders, 12 in. in dia.; each section was flanged for joining to its neighbour, and at the top of the whole was a circular bell and hopper. The bell was supported by a staging clamped to the top of the hopper so that its movement was axial, the fall being controlled by adjustable stops. The primary function of this model was to permit the examination of conditions at or near the stockline, the distance through which the material fell being governed by the height of the selected cylinder and the quantity of material charged. The contents, after discharge from the bell, were sectioned by inserting radial metal vanes or concentric cylinders as carefully as possible, and the material in any particular zone was withdrawn by means of a scoop and

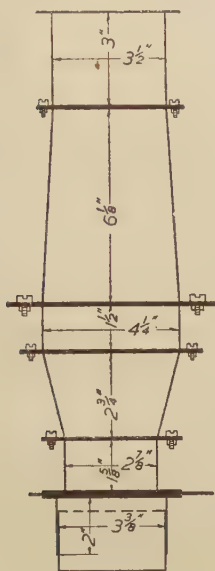


FIG. 2.—Dimensions of Model 2 (ninth scale Frodingham replica).

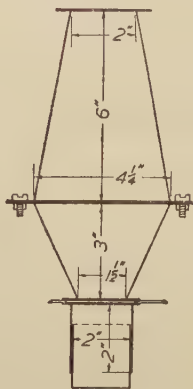


FIG. 3.—Dimensions of Model 3 (with exaggerated lines).

analysed for variation in size by means of sieves or for variation in material by hand picking. It will also be seen later that the circular model had a special use in checking the "charge correction" * when translating the results of other models to larger-scale work. It was soon realized that even with these dimensions large quantities of material were required which had to be discarded after contamination with mixtures of fines; sectioning was laborious and photographic recording unsatisfactory.

Models 2 and 3 were considerably smaller but still circular and, as may be seen from Figs. 2 and 3, consisted of a series of truncated cones and cylinders again fitted with flanges which could be bolted together to make a complete unit, including the bosh and hearth. With the reduced scale greater care was paid to the preservation of a smooth contour within the interior at the joints. It was now possible to study the distribution by

* See Parts II. and III. (to be published later).

preparing wax casts of the contents, and flexibility in design, as demanded by the requirements of particular trials, was preserved. Model 2 was constructed to $\frac{1}{80}$ th scale and was in fact a replica of the furnace at Frodingham, where the field tests had been carried out.* The throughput of material was controlled by a sliding shutter at the base, operated in conjunction with a piston in an extended hearth section; this enabled the contents to be withdrawn in a manner similar to a succession of metal and slag tappings. All relevant dimensions are shown in Fig. 2. A range of bells was provided, again designed for axial motion and controlled depth of fall.

A smaller model, approximately $\frac{1}{80}$ th scale, was similarly constructed, but this was deliberately distorted in respect of its diameter at various levels in order to accentuate normal furnace lines (Fig. 3).

Although eventually natural ore, coke, and limestone were employed exclusively, they were not suitable for the earlier work on waxed casts when sectioning was required. (Pre-sectioning by means of internal partitions before discharging the contents of the bell would differentiate between segregation due to the relative dimensions of the bell and hopper and that which occurs subsequently through displacement after impact; moreover, the frictional forces restricting freedom of movement in the burden would also be changed.) When a stage had been reached in any experiment at which it was desired to fix the contents for examination, the whole unit was carefully removed to a steam chamber and after allowing sufficient time for warming up, molten paraffin wax was poured in at the top until the contents were submerged; after this the whole was allowed to set undisturbed overnight. Withdrawal of the flange bolts enabled the metal sections to be slipped off, the cast being removed and halved or quartered along a random vertical plane.

II.—EXPERIMENTS WITH SPHERICAL MATERIALS.

Lines of Flow in Model 3.

It was first of all desirable to know something concerning the character of the lines of flow of material through the furnace. To do this it was necessary to eliminate any disturbing effects due to blast, but at the same time to preserve as far as possible the buoyancy factor which is associated with it. This could best be realized by the use of spherical material. Spheres provide a limiting case where keying is reduced to a minimum and rolling tendencies are highest. The choice of suitable experimental material was somewhat restricted, and at first seed tapioca, pearl barley, and maple peas were utilized to obtain a suitable range of sizes. Later, when it was desired to approach more closely to the density of the natural materials employed in practice, synthetic aggregates of hematite, limestone, and coke were prepared from the finely ground substances by suitable bonding and moulding into spherical shape in a pill-making machine. These, when used in the waxed models, could be cut with a saw, whereas the same operation was impossible with the natural products. Table I. gives a summary of the relevant physical constants.

Considerable difficulty was experienced in following the flow lines in a model of normal shape such as Model 2, so the first group of experiments was carried out in Model 3, where wall slopes are much exaggerated and the effects become accentuated. The primary function of Model 3 was to reveal the kind of effect likely to be found, and its shape had no other special significance. Its use was restricted to these special cases.

To enable the flow lines to be followed, the model was initially charged

* *The Iron and Steel Institute, 1937, Special Report No. 18.*

with alternate horizontal layers of blue (stained with methylene blue in spirit) and white material, built up in such a way from a knowledge of the volumes of each layer as to give a series of strata of uniform depth. A predetermined amount was then run out at the bottom, the contents fixed in wax, sectioned, and photographed. Thus it was possible to measure displacement of the layers at varying distances from the inwall and stockline.

TABLE I.—*Constants of Spherical Materials.*

Material.	Average Diameter, in.	Sp. gr.	Angle of Repose.	Voids, %.
Tapioca	$\frac{1}{16}$	1.35	33.5°	46.7
Barley	$\frac{1}{8}$	1.34	32°	38.6
Maple peas	$\frac{1}{4}$	1.23	22°	37.8
Hematite	$\frac{1}{8}$	3.13	25°	53.9
Limestone	$\frac{1}{8}$	2.17	27°	53.3
Coke	$\frac{1}{8}$	1.50	28.5°	53.7

Spheres may differ in four ways. They may be of: (a) the same size and density; (b) different size and the same density; (c) the same size and different density; (d) different size and different density. Of these the first three have been considered.

(a) *Material of Same Size and Density.*

The rate of burden movement is likely to vary somewhat from one experiment to another, so it is well to show that scaling down the time factor when working without blast is unnecessary.

Starting with the simplest case, where the particles are uniform and the model is charged with equally deep horizontal layers of alternate colour, one-third of the contents being discharged from the whole area of the base, it will be seen that under ordinary experimental conditions no noteworthy change in the band contours is observed whether the discharge is made slowly (Fig. 38), or quickly (Fig. 39). Indeed, not until the velocity of flow approaches 30 ft./sec. (Fig. 40), is the change significant, whereas normal flow rates are of the order of 1 in. in 10 sec. In Figs. 38 and 39 it is interesting to note that as any layer passes the region of maximum diameter the material at the centre begins to fall more quickly than that at the inwall, and in Fig. 41, where the lowest region was extended by bolting on a subsidiary 2-in. cylinder, the initial layer pattern has moved through 90° by the time it reaches the hearth, owing to frictional forces at the walls. Further analyses of these records and that under (b) below are illustrated graphically in Figs. 4-7, which show the relationship between the final position of a particle and its vertical displacement during the experiment. In each graph the lines corresponding to successive layers are numbered from the top downwards, and for the sake of clarity those below the maximum diameter are dotted. There is a general movement towards the centre in the lower part of the model, which is perhaps more clearly shown by arranging the initial packing vertically instead of horizontally. To this end cylindrical paper separators were suitably arranged in position; white spheres were introduced into the annulus and coloured spheres within and without until charging was complete; the paper was then carefully withdrawn and the discharge made. In Fig. 42 the white annulus was originally of 1 in. internal and 1½ in. external dia., and, after one-third discharge before setting in wax, the movement towards the centre in the lower half is distinctly visible and even extends to coalescence near the base. More-

over, in the upper portion the annular ring has spread slightly towards the walls.

(b) *Materials of Same Density but Different Sizes, Discharged as Before.*

On repeating the above experiments, but commencing with equal layers of peas and barley, the first thing which became apparent (Fig. 43) was

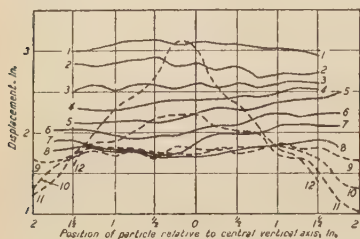


FIG. 4.—Slow Discharge Rate.
(Cf. Fig. 38.)

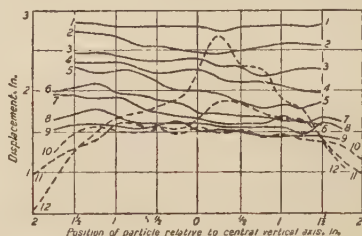


FIG. 5.—Fast Discharge Rate.
(Cf. Fig. 39.)

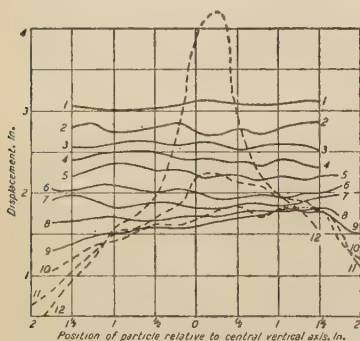


FIG. 6.—Extended Hearth.
(Cf. Fig. 41.)

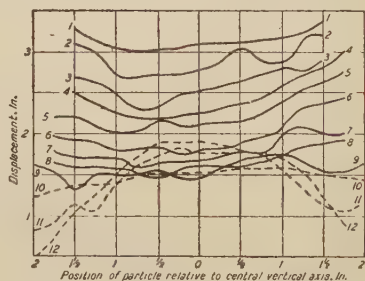


FIG. 7.—Materials of Different Size.
(Cf. Fig. 43.)

FIGS. 4-7.—Relation between the Final Horizontal Position of a Particle and its Vertical Displacement.

the greater convexity upwards of the top portion of the patterns, and it would seem that this was at any rate partly due to the decreased frictional effect of the walls on the larger material. Again, in the lower half, the less well-defined V penetration of adjacent layers might have been due to the same cause (see Fig. 7).

(c) *Materials of Same Size but Different Density.*

These are considered in the section on Layer Charging.

Lines of Flow in Model 2.

The effect of reducing the exaggerated lines was to preserve greater uniformity of the layers in the upper portion of the model (Fig. 44), but once again after passing the level of maximum diameter the displacement increased towards the centre and gave a pattern similar (yet without such acute V form) to those previously obtained.

Distribution in Model 2.

In Fig. 45 the model was first filled with barley and then for each withdrawal at the base a similar volume of 1 : 1 mixture of barley and peas was introduced from a 90° bell, 2½ in. in dia., the process being repeated until the new burden was discharging at the base; the materials were then fixed in wax and sectioned. Definite segregation of the larger material towards the centre is indicated. Here the final pattern is complicated by the fact that segregation has occurred not only within the stack as a result of flow but also during the fall to the stockline.

At this stage it may be desirable to point out that two main problems are involved: (1) The factors which determine the stockline contour, and (2) the flow lines of a particle through the stack; and that both are inter-related. The stockline at any moment is being built not on a horizontal descending layer, but upon one whose configuration is constantly changing according to the time interval between successive discharges from the base. Moreover, as the stockline falls the path of the discharged burden is increased, and this again accentuates some aspects of the distribution. For this reason it is more convenient to commence in many of the experiments with an artificial stockline of the simplest form, *viz.*, horizontal, from which the more complicated cases may be derived.

The Slice Model (Model 4).

It was realized that much more extensive information might be obtained if it were possible to view the instantaneous pattern of the distribution, and this led to a revision in design. Model 4 (Fig. 8a) is essentially a glass-

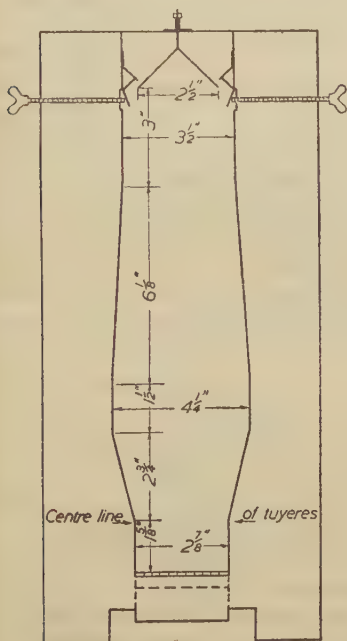


FIG. 8a.—Section through Model 4 (the slice model).

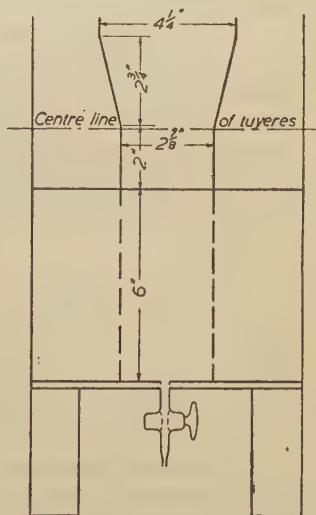


FIG. 8b.—Modified Base of Model 4.

sided vertical section through Model 2, constructed to the same scale ($\frac{1}{60}$ th) as before. It was built of wood on a suitable base and fitted with a sectioned metal bell, also to scale. By suitable modification, the scope of Model 2 was extended; the discharge orifice, for example, was closed by a number of brass slides running in guides and working independently, so that the effects due to wastage of coke at or in front of the tuyeres could be simulated in addition to the normal type of discharge (tapping of metal), when the multi-slide shutter was replaced by a single-slide one, covering the full aperture. This model was further improved by a modified base housing a reservoir of mercury (Fig. 8b) on which the burden floated, so permitting greater ease of operation and accuracy of control in that volume displacements were measurable. The walls were covered with fine glass-paper to give a nearer approach to the frictional effects of the partly worn lining which is to be expected in practice. In addition, provision was made above the stockline for the introduction of adjustable batter plates,* and at the top for a suitable mounting to accommodate bells of various sizes and shapes, each with a controlled depth of fall. As the front and back of the model were transparent, any stage of the experiment could be visually followed and photographed as and when desired, without the necessity for waxing and its attendant disadvantage of interruption and repetition for sequence pictures. A two-sided view of the progress of distribution permitted the intervention of adventitious asymmetry to be instantly detected, though this was fortunately a rare occurrence. After comparison tests the effects of various factors were again studied in groups until an extensive field had been covered. The "slice" model suffers from only one drawback: since it is of uniform thickness from front to back, the diametrical scale is not accurately preserved. As, however, a correction for this can easily be applied its advantages are obvious.

Experimental data are best considered in relation to specific changes in operation.

Fig. 46 shows a repeat of the concentric charging experiment with normal furnace lines, using materials of equal size and density after gradually running through about one-third of the burden and replenishing at each stage to a constant height. The effects previously noted are still present but less marked. The width of the blue core increases from $1\frac{1}{2}$ in. at the stockline to $1\frac{3}{4}$ in. about one-third of the way down, after which the taper is almost uniform to the base, where the width is 1 in.

Summary of Variables.

The variables are best considered in relation to their origin; some are associated with the materials and others with the furnace design; moreover, they may co-exist in a great variety of combinations.

Burden.	Variables.	Furnace Design.
Size. Shape. Density. Moisture content.†	Considered— (a) without blast. (b) with changes in blast pressure and volume.† (c) in relation to tuyere combustion zones.† (d) in relation to charging cycles.†	Bell angle. Bell drop. Rate of bell opening.† Bell/throat ratio. Bell overhang.† Batter. Stockline position. Wall surface (rough and smooth).†

In the following experiments the lower two-thirds of the model were filled with a neutral burden to a horizontal stockline. Alternate chargings

* In the text "batter" refers to the general shape of the furnace immediately beneath the rim of the bell.

† These items will be considered in Part II.

were made from the selected bell of coloured and white material until the stockline was at its normal position. About one-third of the contents was run through in the usual way, the stockline level being maintained with new additions from the bell. The pattern was then photographed. The interchangeable bells differed only in apex angle, the diameters at the base being constant, and the overhang just adequate to ensure closure in the raised position.

Variation of Bell Angle.

Apex angle	60° (Fig. 47).
„	70° (Fig. 48).
„	80° (Fig. 49).
„	90° (Fig. 50).
„	100° (Fig. 51).

Although in this series the angle of the bell was varied over 40° the distributions remained similar. Indeed, whether the pattern be examined at the stockline or at corresponding distances below it, differences are relatively small and do not show a regular change. At the lower levels there is a general tendency towards uniformity.

Variation of Batter.

The bell angle was kept constant at 90°; as before, materials were charged to the stockline and discharges were made good.

Batter plates at	0° (Fig. 50).
„	22½° (Fig. 52).
„	45° (Fig. 53).

Whereas the change in pattern produced by wide variations in the angle of the bell are comparatively small, alterations in the slope of the batter plates are attended by marked effects. In the top region in Fig. 50 the V pattern is maintained for the full twelve layers charged. In Fig. 52 it will be noted that whilst the V pattern has been partially kept, it becomes less clearly defined with descent, and merges into a shallow M formation by the time the twelfth layer is reached. In Fig. 53 the M pattern is retained throughout some nine or ten layers, after which it is so flattened at the centre as to approximate to a shallow inverted V.

It should be remembered that in the initial charging the distances through which the particles fell diminished successively as the first half-dozen layers were built up, and hence the next group of experiments was carried out to trace the trajectories and points of impact on a stockline at various distances below the bell. Figs. 54–57 were taken with the batter plates at 0°, 15°, 30°, and 45°, respectively. These records are of special interest in showing the convergence of the streams and the degree of spread and, in addition, the density of distribution at various levels. On comparing the figures with those in Figs. 50, 52, and 53, the reasons for the difference in the contours obtained become apparent, and it would seem that when considering particles of the same size and density, a large measure of control may be exercised by alterations in batter.

Influence of Moisture.

The normal procedure after staining with methylene blue in spirit was to dry the material thoroughly on a steam bath; in one instance, when a repeat on Fig. 53 was required, an entirely new pattern made its appearance and this was traced to insufficient drying (Fig. 58). Although in this case it was only alternate layers which were thus affected, the result had been to impose a distortion on the dry materials as well, so that the whole pattern was thereby changed. Confirmation of this effect of moisture is obvious from an examination of Figs. 50 and 59, the latter being a repeat

of the former but with partially dried materials. The asymmetry of the pattern in the middle layers is probably due to local differences in moisture content. The issue raised is one of considerable interest and will be referred to again in a later part.

Distribution.

Fig. 60 shows the model, initially filled from the bell with an intimate mixture of coke and hematite spheres (batter plates vertical), with charge and discharge continued until about one-third throughput. The analysis of the distribution by particle counts is given in Table II.

TABLE II.—*Number of Hematite Spheres in Various Portions of Stack (V Stockline; cf. Fig. 60).*

Six vertical sections numbered 1 to 6.

Twelve horizontal sections numbered A to L.

	1.	2.	3.	4.	5.	6.
<i>A</i>	27	10	6	5	20	23
<i>B</i>	30	22	13	19	26	41
<i>C</i>	24	27	18	22	24	35
<i>D</i>	27	31	29	22	20	38
<i>E</i>	29	29	24	20	30	34
<i>F</i>	30	22	21	19	20	39
<i>G</i>	39	27	16	19	32	34
<i>H</i>	34	34	25	25	26	33
<i>I</i>	28	30	23	20	23	29
<i>J</i>	26	25	20	19	29	29
<i>K</i>	...	34	18	20	30	...
<i>L</i>	...	30	26	27	33	...

It is apparent upon inspection that segregation has occurred both immediately below the bell and during the descent of the burden, for there is, generally speaking, a concentration of coke towards the centre, which, however, becomes less well defined as the maximum diameter of the stack is approached. In Fig. 61, where the only change made was in the angle of the batter plates, now 45°, the central column of coke is even more noticeable. The results of particle counts are given in Table III.

TABLE III.—*Number of Hematite Spheres in Various Positions of Stack (M Stockline; cf. Fig. 61).*

Six vertical planes numbered 1 to 6.

Twelve horizontal planes numbered A to L.

	1.	2.	3.	4.	5.	6.
<i>A</i>	30	30	14	17	17	20
<i>B</i>	25	29	19	18	25	17
<i>C</i>	26	29	21	16	23	21
<i>D</i>	26	31	13	18	31	25
<i>E</i>	38	28	15	16	28	25
<i>F</i>	27	30	17	17	22	23
<i>G</i>	28	29	22	26	25	24
<i>H</i>	25	31	26	26	19	23
<i>I</i>	20	31	18	22	23	19
<i>J</i>	23	26	30	23	19	...
<i>K</i>	...	23	25	21	18	...
<i>L</i>	...	30	22	31	17	...

Fig. 9 shows the number of hematite spheres near the stockline for various horizontal positions across the stack, and it is interesting to observe how the density of distribution follows the stockline contour in each case.

Hearth Conditions.

In all previous experiments the bottom slide covered the full area of the aperture. This would correspond in practice to normal tapping, but takes no account of additional wastage due to combustion of coke in front of the tuyeres. The exact location of this combustion zone cannot be stated with certainty; its position has therefore been successively changed from the wall to the centre in the following series in five steps (Figs. 62–66).

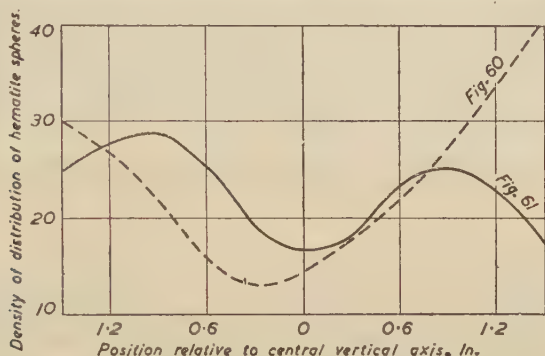


FIG. 9.—Variation of Number of Hematite Spheres near Stockline across the Stack.

The model was initially two-thirds charged with horizontal layers of dark and light materials, and then filled to the stockline from a 90° bell with batter plates vertical. As the discharge was carried out an equivalent volume of material was added. Of the eleven slides symmetrical pairs were operated as follows :

Slides drawn	1, 2, 10, 11 (Fig. 62).
" "	2, 3, 9, 10 (Fig. 63).
" "	3, 4, 8, 9 (Fig. 64).
" "	4, 5, 7, 8 (Fig. 65).
" "	5, 6, 7 (Fig. 66).

In each case it will be noted that the conditions give a stockline of V formation, and as the discharge area moves from the wall to the centre the pattern changes accordingly. In Fig. 62 the lines of maximum flow, at any rate in the lower half of the model, are situated near the walls, and they gradually move nearer the centre as the shutters operated move in like direction (Figs. 63–66). Moreover, in the top half the pattern remains much the same in Figs. 62–64, and only as discharge becomes more localized, in Figs. 65 and 66, is the V pattern extended and accentuated. It is only when the natural lines of flow and those particularly associated with the position of the operated slides mutually assist one another that the influence is felt higher up in the stack.

Layer Charging.

A further series of examples (Figs. 67–70) has been included to illustrate the effect of changing the batter angle when cyclic-layer charging is carried out, spherical hematite, coke, hematite, coke, limestone, being run through in the usual way. The stockline contours are preserved for a

considerable depth, but there are no very marked differences apparent due to density changes when spheres of different density are charged separately. (*See ore/coke cycles, Part II.*)

So far only spherical particles have been considered, and apart from the influence of moisture, there has been little evidence of slip, bridging, or formation of chimneys. The moisture series suggests that these effects will tend to increase as interparticulate friction rises.

Reviewing the behaviour of spherical material, it will be noted that the most pronounced changes occur in conjunction with the interposition of deflecting surfaces between the stockline and the rim of the bell. Furnaces vary a little in shape in the upper stack region and also in the design of protecting plates for the top inwall. Any kind of surface is liable to undergo changes during the life of the furnace, particularly when submitted to continuous abrasion by falling material, erosion from the dust of the exit gas, and also the relatively slow chemical changes over an extended period of time. Thus a change in the distribution might be anticipated as the furnace ages.

Moisture is responsible for alterations in the flow irrespective of the initial distribution, and there often is some distortion of regularity in the patterns.

III.—EXPERIMENTS WITH MATERIALS OF IRREGULAR SHAPE.

It is next necessary to consider the behaviour of irregular particles. The first point of note is that freedom of movement after impact is greatly restricted; this is well illustrated by a comparison of the angles of repose for spheres and irregular particles. Differences of the order of 10° or more will be found. When it is realized that these values obtain with open heaps of material, it will be appreciated that when rolling is restricted by the walls or even local differences in level, such effects are likely to be considerably accentuated. Lines of flow through the model with irregular particles become so much more complex, attended by slip and bridging, that it will be necessary to devote a special section to this part of the work; it is more satisfactory to deal in the first instance with distribution and for the sake of clarity to treat the observed effects under slightly different groupings.

Table IV. shows the relevant physical constants.

TABLE IV.—*Physical Constants of Irregular Materials.*

Material.	Average Diameter, mesh.	Density.	Angle of Repose, degrees.	Voids, %.
Hematite .	10-20	4.0	37.5	47.0
" .	20-40	4.0	36	48.0
" .	40-60	4.0	35.5	49.0
Limestone .	10-20	2.6	39.5	47.5
" .	20-40	2.6	37.5	45
" .	40-60	2.6	37	46.5
Coke .	10-20	1.25	40	52
" .	20-40	1.25	38.5	50
" .	40-60	1.25	37.5	43
Porcelain .	10-20	2.3	39	60
" .	20-40	2.3	37.5	56
" .	40-60	2.3	37	58

(A) *Derivation of Stockline Contour.*

Lines of flight have been recorded covering the full height of the model, their object being two-fold: In the first place they render possible the differentiation of any distributive effects due to movement after impact at the stockline, from those associated only with discharge from the bell. Secondly, by drawing an imaginary line across any diagram at a selected level, the form of the stockline contour may immediately be envisaged. For example, in Fig. 10 let the vertical dotted lines represent the width of the streams at the selected position; from the mean point of the stream draw the sloping lines $A'A$ according to the angle of repose of the material in question; then draw parallel lines to these, intersecting near the centre, still keeping each apex at the centre line of flight; complete the figure by drawing the outer sloping lines $B'B$ parallel to the first ones. This gives the derived stockline contour. By way of comparison, the actual stockline in this particular case was *CCCC*.

In addition to the series of photographs results are further summarized

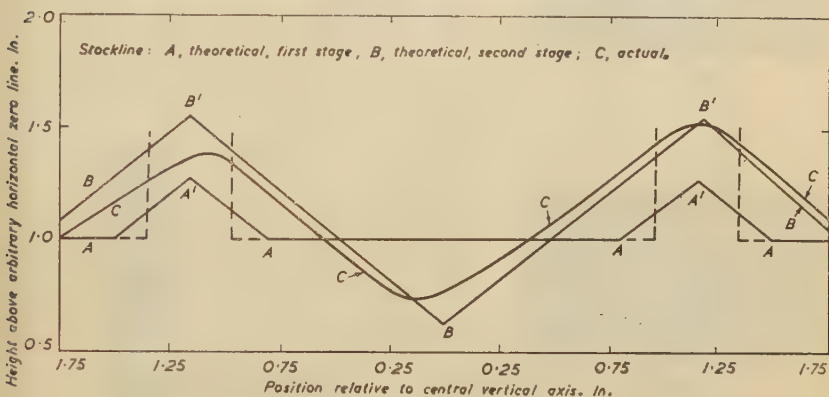


FIG. 10.—Derivation of Stockline Contour.

in graphs showing the mean paths of falling particles in relation to their positions in the stack.

It will be seen that the individual trajectories vary considerably with the character of the materials used and with the furnace lines; some are relatively narrow, others more diffuse. The density of the particle distribution within the streams is not necessarily uniform, and general broadening occurs with increased fall owing to scatter. Allowance can be made for such items as these in conjunction with variations in angles of repose in devising the initial stockline form, and also the best way of filling a new or relined furnace for blowing in.

Consider now the individual significance of making a single change relating to the materials, with furnace design remaining unaltered, as follows: Scale $\frac{1}{60}$ th linear; bell angle 90° , bell drop $\frac{3}{8}$ in., bell/throat ratio 0.72, and batter 30° ; the last is a purely arbitrary choice to secure good differentiation.

(B) *Discharge of a Homogeneous Burden.*(1) *Variations in Materials.*

(a) *Size Variation* (Fig. 11).—Particles of irregular shape, same density but varying size: $\frac{1}{8}$ in. (Fig. 71), 10/20 mesh (Fig. 72), 20/40 mesh (Fig. 73),

and 40/60 mesh (Fig. 74). It will be seen that as the size decreases the path of the streams approaches the vertical more closely, and hence the point of confluence is gradually lowered. The stockline under these conditions will be of the M type and the ridges approach closer to the walls as the size diminishes, giving a larger central trough.

(b) *Shape Variation* (Figs. 12 and 13).—Furnace lines as under (a); $\frac{1}{8}$ in. spherical and irregular material (density 2.2) (Figs. 75 and 76); $\frac{1}{16}$ in. spheres and 10/20 mesh irregular material (density 1.3) (Figs. 77 and 78). These four records illustrate the effects of the variation in shape. First there is increased scatter with the particles of irregular shape, so that on the primary distribution alone a shallower contour would be expected. Since, however, rolling is minimized with irregular particles owing to friction, the differences tend to oppose and actually the latter effect predominates. The trajectory of the irregular material is also nearer the vertical; this is probably due to the increased frictional forces on the bell.

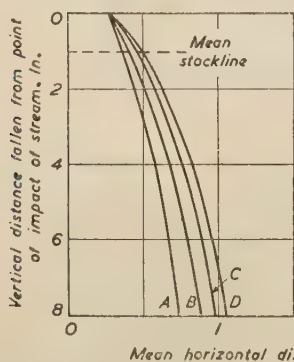


FIG. 11.—Porcelain: A, 40/60 mesh; B, 20/40 mesh; C, 10/20 mesh; D, 6/10 mesh.

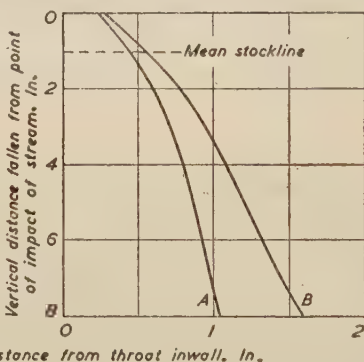


FIG. 12.—A, Irregular porcelain; B, limestone spheres, $\frac{1}{8}$ in.

FIGS. 11 and 12.—Variation of Mean Stream Path with Particle Size and Shape.

Its kinetic energy at the bell rim is less than in the case of spheres and consequently the outward component of its velocity is diminished.

(c) *Density Variation* (Fig. 14).—Materials used: coke, limestone, and hematite (Figs. 79, 80, and 81, respectively); other variables as under (a); $\frac{1}{8}$ in. spheres. It will be seen that the differences in the mean flow lines are relatively small, but there is a diminution of scatter with increasing density.

Figs. 11–14, which are self-explanatory, summarize the mean lines of flight in this section according to the nature of the variables and are supplementary to the photographic records.

(2) Variation in Furnace Top Design.

Throughout this section the size, shape, and density of the particles remain the same, while changes relating to the furnace are considered seriatim.

(a) *Bell-Angle Variation* (Fig. 15).—A number of examples dealing with spherical particles have already been mentioned, and it was shown that the mean lines of flight are only slightly different for wide alterations in bell angle. A comparison of Figs. 82 and 83 (apex angles 90° and 60°

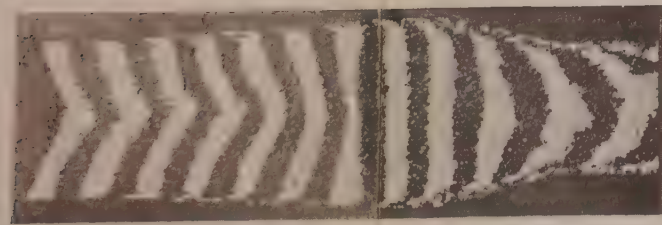


FIG. 50.



FIG. 51.



FIG. 52.

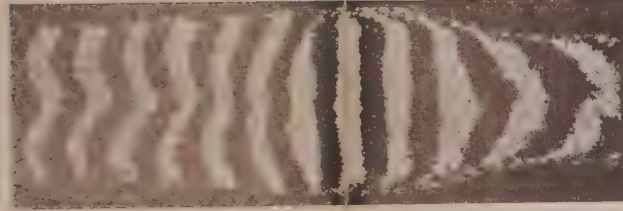


FIG. 53.

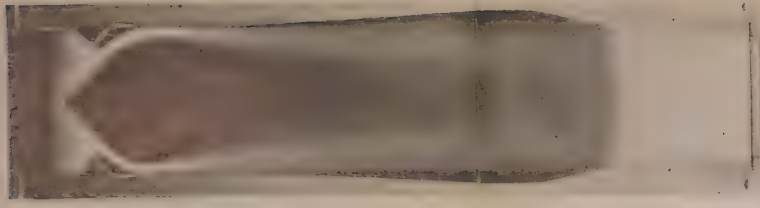


FIG. 54.

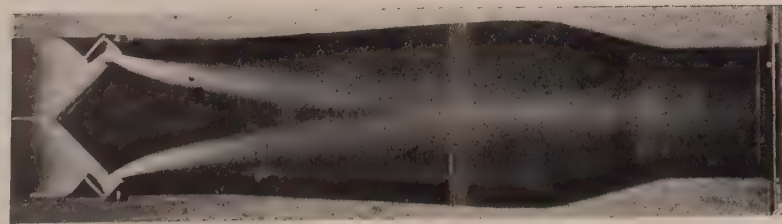


FIG. 55.

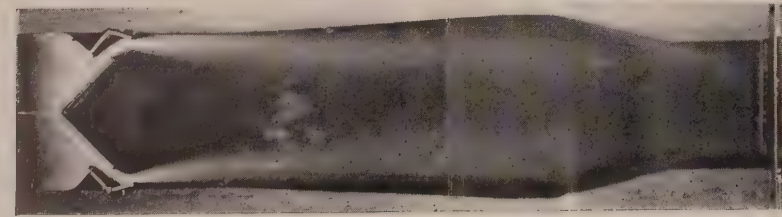


FIG. 56.

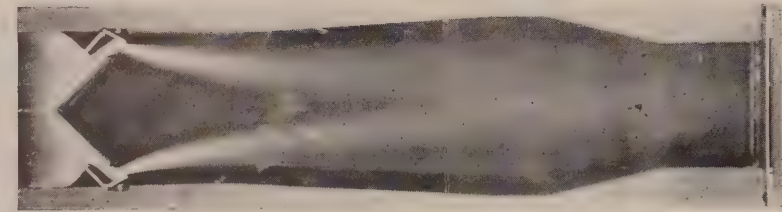


FIG. 57.

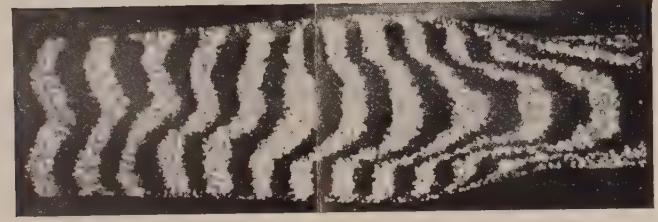


FIG. 58.



FIG. 59.

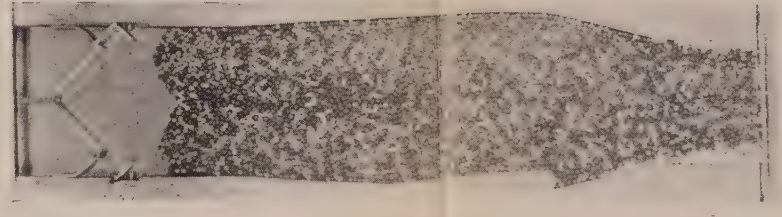


FIG. 60.

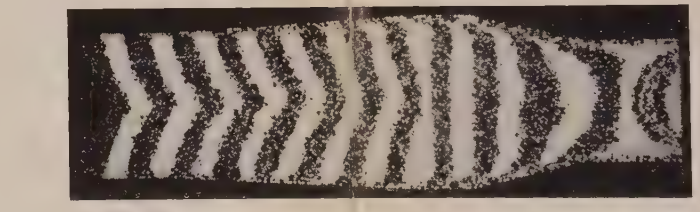


FIG. 61.

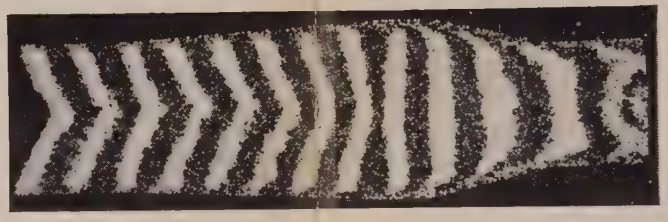


FIG. 62.



FIG. 63.

FIG. 64.

Figs. 50 and 51 (see also Figs. 47 to 49).—Effect of Bell-Angle Variation on Distribution. Bell angle: FIG. 50, 90°; FIG. 51, 100°. Figs. 52 and 53.—Effect of Batter-Angle Variation on Distribution. Batter angle: FIG. 52, 22½°; FIG. 53, 45°. cf. FIG. 50 (0°). Figs. 54 to 57.—Streaming Experiments: Effect of Variation of Batter. Batter angle: FIG. 54, 0°; FIG. 55, 15°; FIG. 56, 30°; FIG. 57, 45°. Figs. 58 and 59.—Effect of Moisture Content on Distribution. FIG. 58, batter angle 45°; cf. with FIG. 53 (dry); FIG. 59, batter angle 0°; cf. with FIG. 50 (dry). Figs. 60 and 61.—Distribution with a Two-Density Mixture. FIG. 60, V stockline; FIG. 61, M stockline. Figs. 62 to 64 (see also 65 and 66).—Flow Lines with Varied Hearth Conditions. Peripheral discharge in FIG. 62 gradually changes to centre discharge in FIG. 66.

DISTRIBUTION OF MATERIALS IN THE BLAST FURNACE.

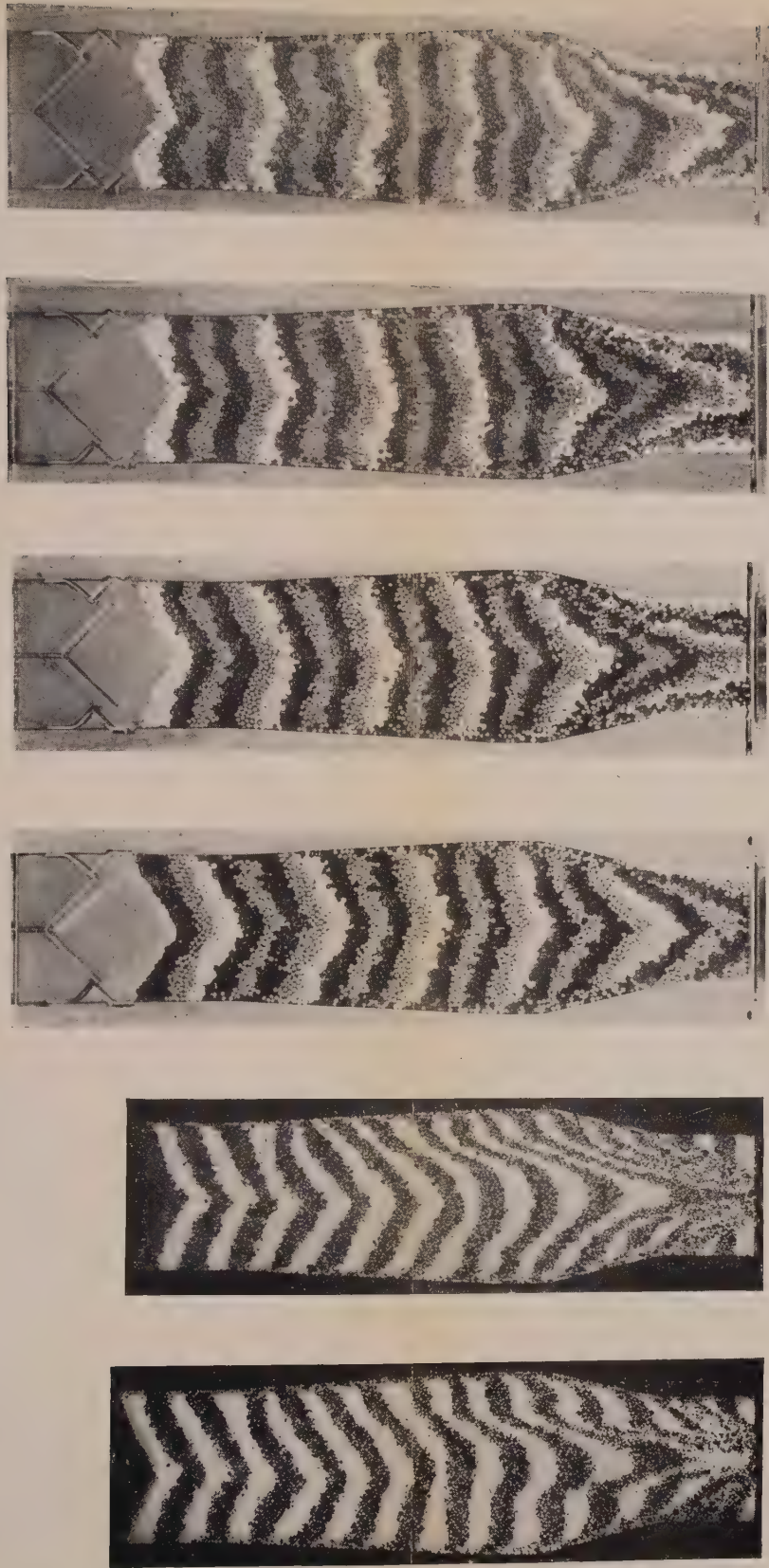


FIG. 65.

FIG. 66.

FIG. 67.

FIG. 68.

FIG. 69.

FIG. 70.

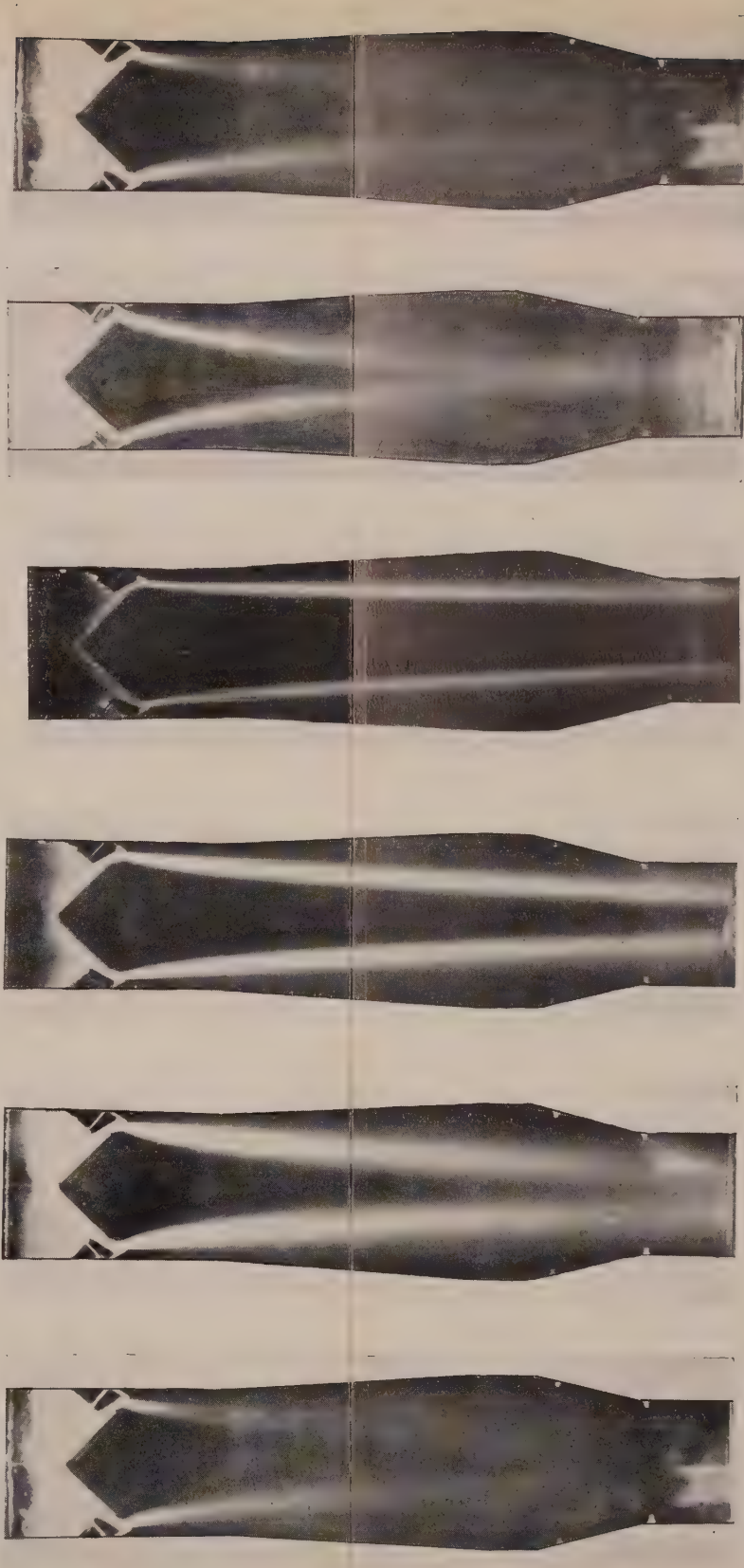


FIG. 71.

FIG. 72.

FIG. 73.

FIG. 74.

FIG. 75.

FIG. 76 (same as Fig. 71).

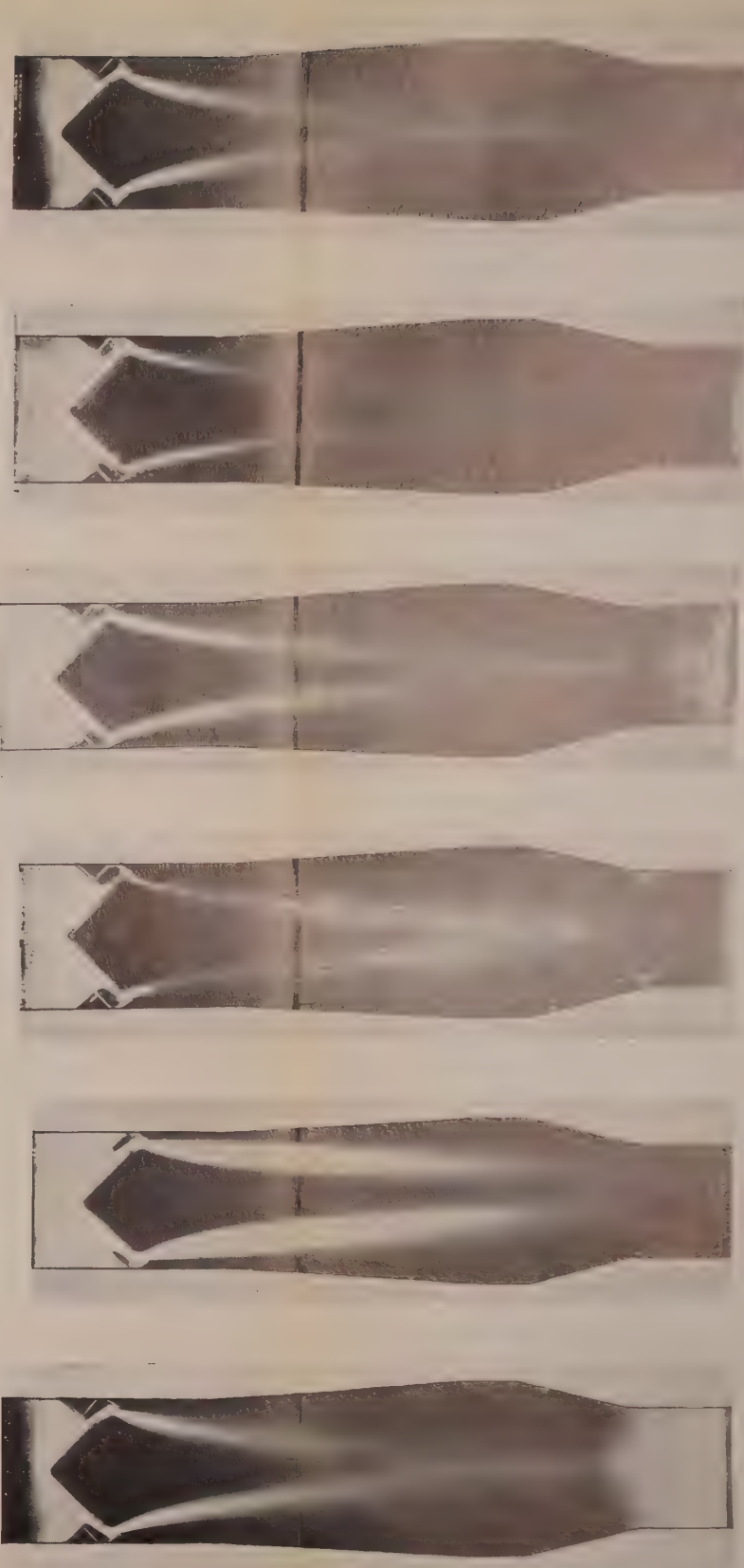


FIG. 77.

FIG. 78.

FIG. 79.

FIG. 80.

FIG. 81.

FIG. 82.

Figs. 65 and 66 (see also 62 to 64).—Flow Lines with Varying Density Layers. Effect of In-crease in Density Layer. Size: Fig. 65, 1 in.; Fig. 66, 1 in.; Fig. 67, 1 in.; Fig. 68, 1 in.; Fig. 69, 1 in.; Fig. 70, 1 in.; Fig. 71, 1 in.; Fig. 72, 1 in.; Fig. 73, 1 in.; Fig. 74, 1 in.; Fig. 75, 1 in.; Fig. 76, 1 in.; Fig. 77, 1 in.; Fig. 78, 1 in.; Fig. 79, 1 in.; Fig. 80, 1 in.; Fig. 81, 1 in.; Fig. 82, 1 in.

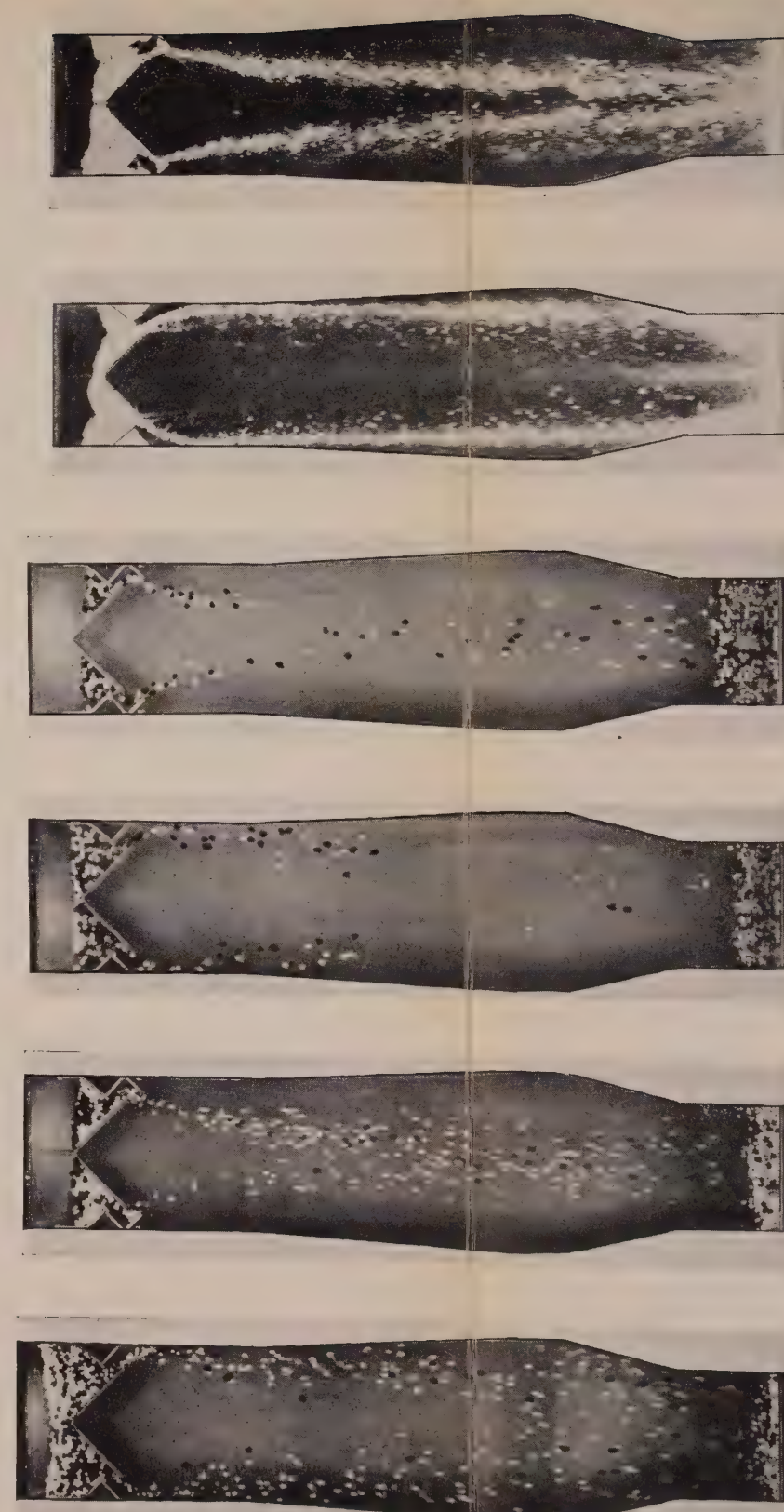
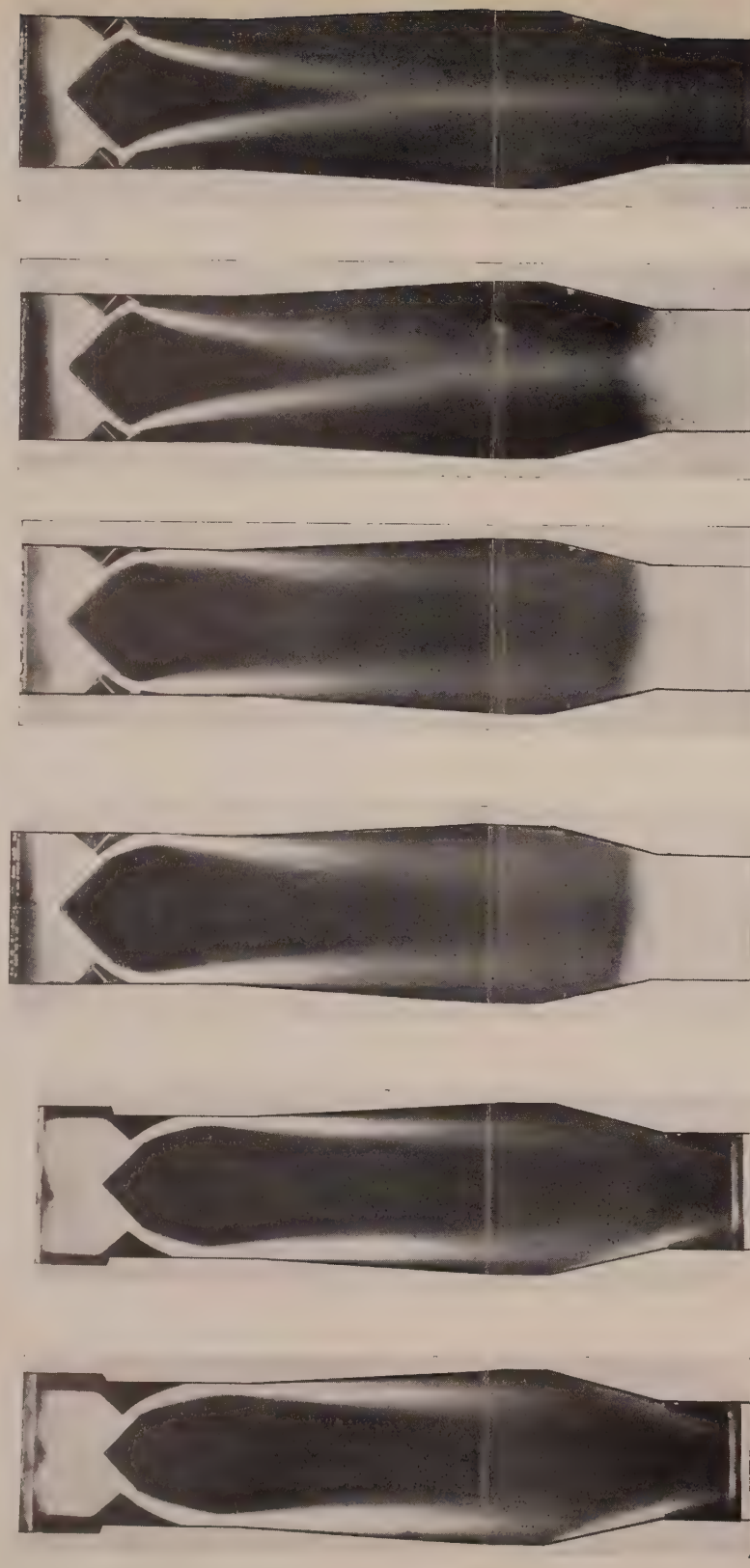
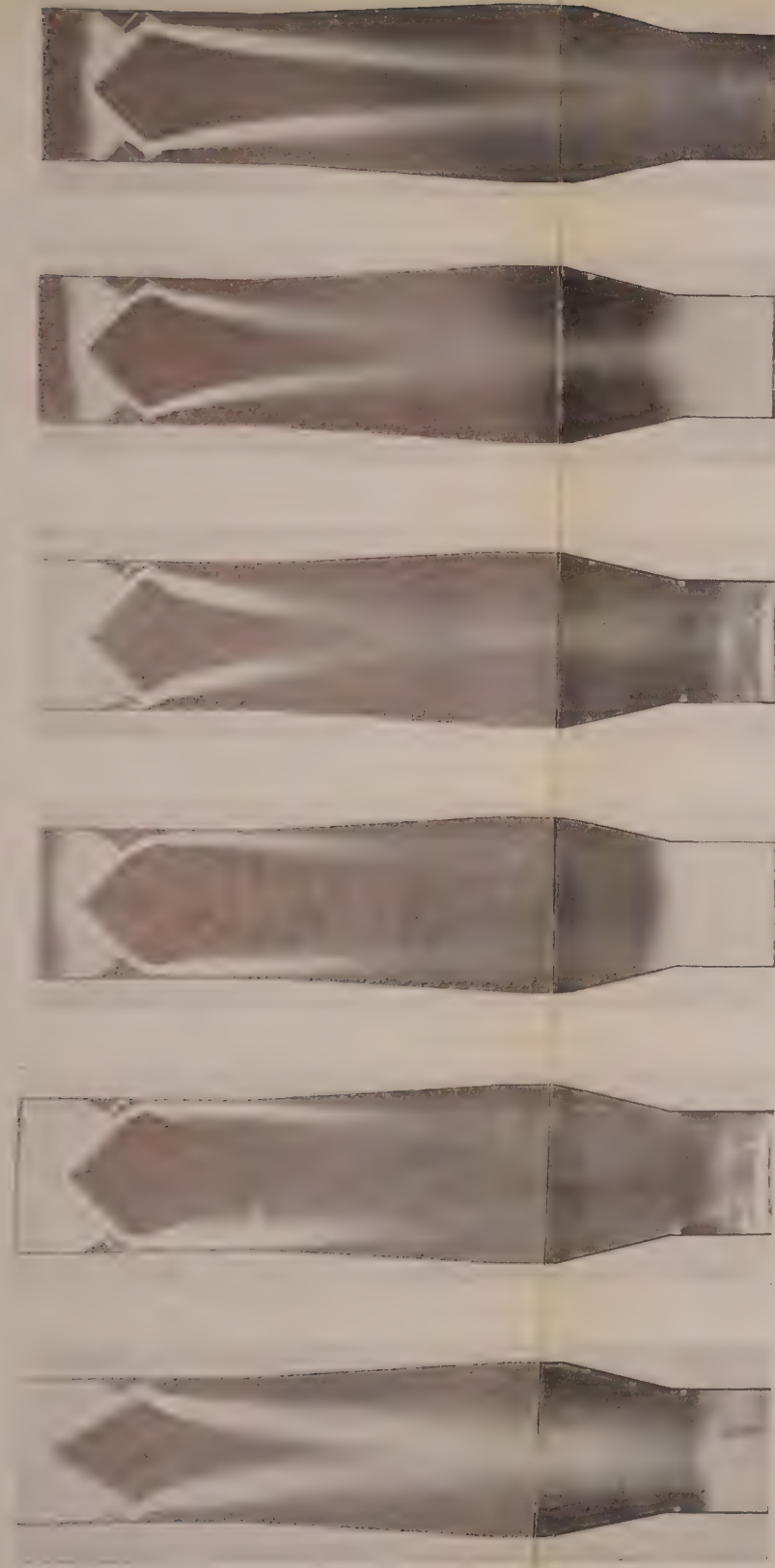


Fig. 83 (see also Fig. 82).—Effect of Variation of Bell Angle on Distribution. Bell angle: 60° . Figs. 84 and 85.—Effect of Variation of Bell Drop on Distribution, with a Batter Angle of 15° . Bell drop: Fig. 84, $\frac{1}{4}$ in.; Fig. 85, $\frac{3}{8}$ in. Figs. 86 to 88.—Effect of Variation of the Bell/Throat Ratio on Distribution. Ratio: Fig. 86, $\frac{1}{4}$ in.; Fig. 87, $\frac{3}{8}$ in.; Fig. 88, $\frac{1}{2}$ in. Figs. 89 to 91.—Effect of Variation of Batter Angle on Distribution. Batter angle: Fig. 89, 0° ; Fig. 90, 15° ; Fig. 91, 30° . Figs. 92 and 93.—Effect of Variation of Size in a Mixed Burden ($\frac{1}{4}$ and $\frac{3}{8}$ in. spheres). Batter angle: Fig. 92, 0° ; Fig. 93, 45° . Figs. 94 and 95.—Effect of Variation of Density in a Mixed Burden. Batter angle: Fig. 94, 0° ; Fig. 95, 45° . Figs. 96 and 97.—Effect of Variation of Size of Irregular Particles (10/20 and 40/60 mesh) in Mixed Burden. Batter angle: Fig. 96, 0° ; Fig. 97, 45° . Figs. 98 and 99.—Effect of Variation of Density in a Mixed Burden. Batter angle: Fig. 98, 0° ; Fig. 99, 45° . Fig. 100.—Effect of Variation of Density in a Mixed Burden. Batter angle: Fig. 100, 45° .

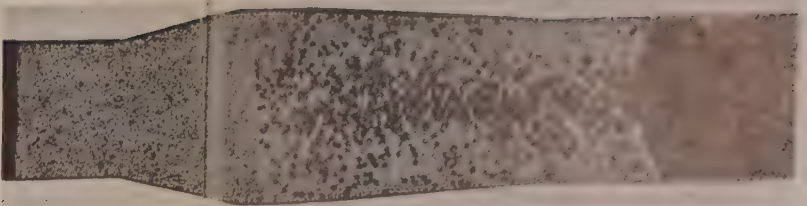


FIG. 117.

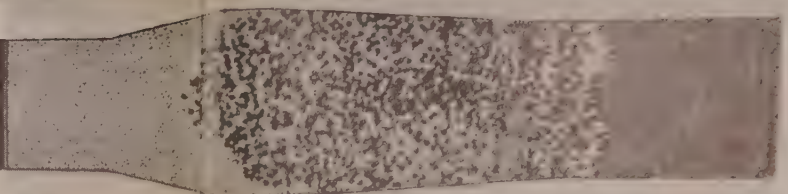


FIG. 118.

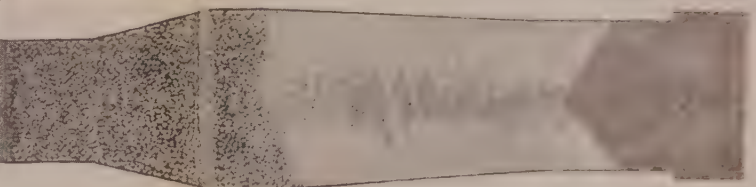


FIG. 119 (same as Fig. 112).

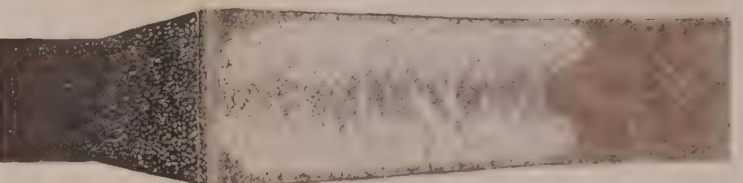


FIG. 120.

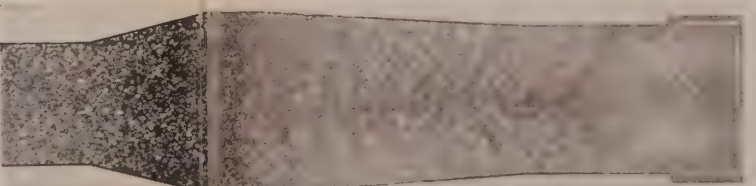


FIG. 121.



FIG. 122.



FIG. 123 (same as Fig. 60).

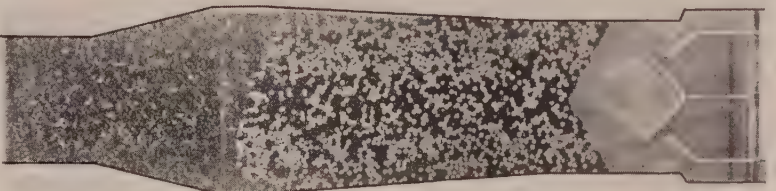


FIG. 124.

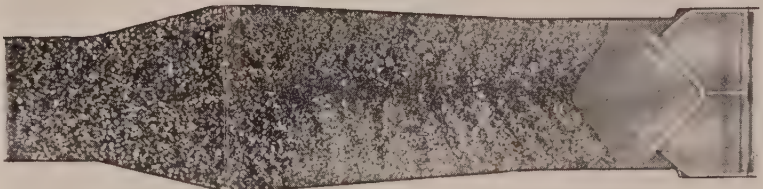


FIG. 125.

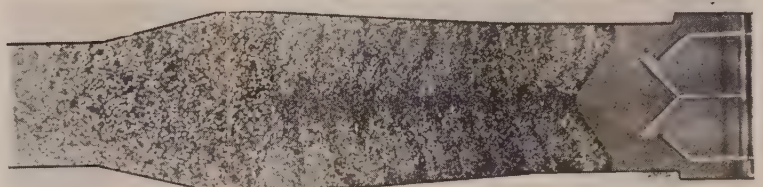


FIG. 126.

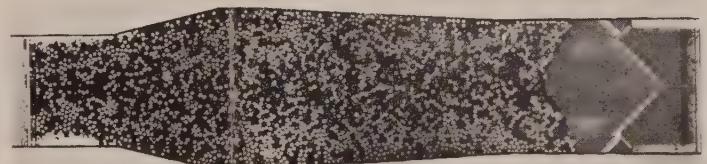


FIG. 127 (same as Fig. 60).



FIG. 128 (same as Fig. 61).

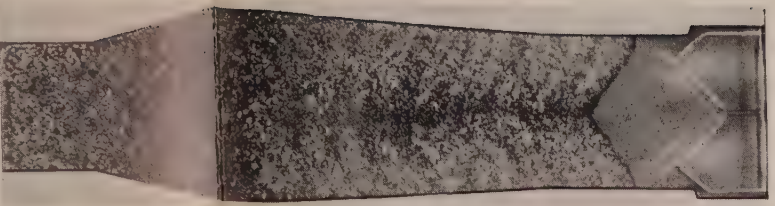


FIG. 129 (same as Fig. 121).



FIG. 130.

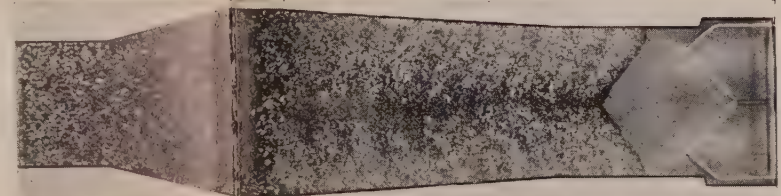


FIG. 131 (same as Fig. 121).

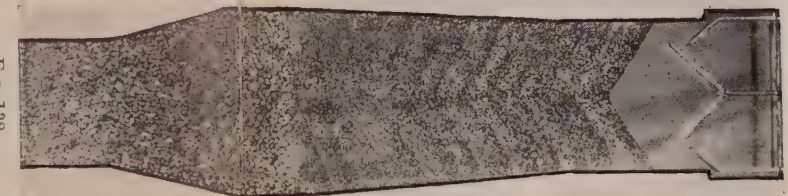


FIG. 132.



FIG. 133.

respectively) will, however, illustrate the extended scatter with the 60° bell resulting *per se* in shallower ridges at the stockline. Although the bell drop in both cases is unchanged, the discharge orifice is relatively smaller with the 60° bell. (For convenience of illustration the batter is set at 45° .)

(b) *Bell Drop Variation* (Fig. 16).—Variations of bell drop ($\frac{1}{4}$, $\frac{3}{8}$, and

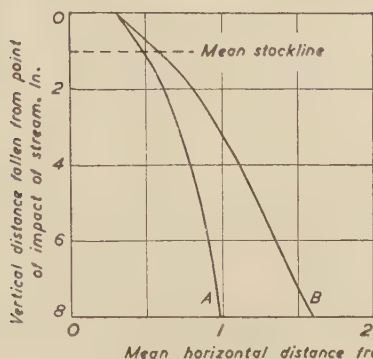


FIG. 13.—Shape: A, irregular; B, spherical.

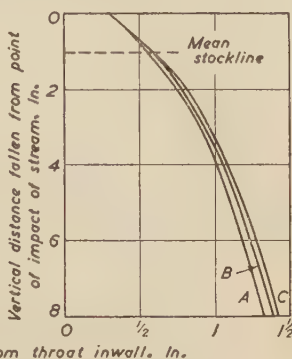


FIG. 14.—Density: Spheres of A hematite (sp. gr. 3.13), B limestone (2.17), C coke (1.50).

FIGS. 13 and 14.—Variation of Mean Stream Path with Shape and with Density of Particles.

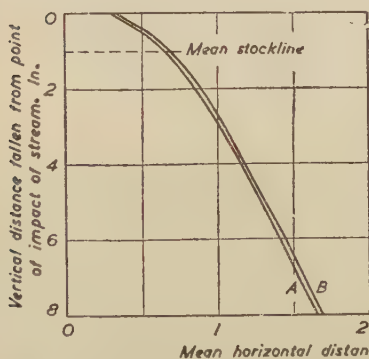


FIG. 15.—Bell angle: A, 60° ; B, 90° .

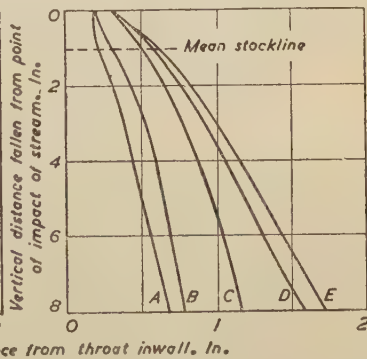


FIG. 16.—Bell drop and batter angle: A, $\frac{3}{8}$ in., 15° ; B, $\frac{1}{4}$ in., 15° ; C, $\frac{1}{2}$ in., 30° ; D, $\frac{3}{8}$ in., 30° ; E, $\frac{1}{4}$ in., 30° .

FIGS. 15 and 16.—Variation of Mean Stream Path with Angle and Drop of the Bell.

$\frac{1}{2}$ in.) have been made corresponding to 15, $22\frac{1}{2}$, and 30 in. in full scale and two batter angles selected for illustration.

Figs. 84, 85: Bell drop $\frac{1}{4}$ and $\frac{3}{8}$ in., batter angle 15° .

Figs. 86, 87, and 88: Bell drop $\frac{1}{4}$, $\frac{3}{8}$ and $\frac{1}{2}$ in., batter angle 30° .

The first point of note is that the fall of the particles becomes more vertical as the bell drop is increased, and this applies irrespective of batter angle. In the same way scatter diminishes as the discharge orifice widens,

and it would seem reasonable to suppose that this is due to increased velocity as the charge leaves the bell. Changes in internal frictional forces at the orifice are mainly responsible for the differences observed. From Fig. 16 it is evident that the effects are quite regular, and they suggest the possibility of combining bell drop and batter changes as a pair of compensating variables (see also Fig. 18).

(c) *Bell/Throat Ratio Variation* (Fig. 17).—As the bell/throat ratio diminishes the point of impact of the falling material with the inwall also falls, so that batter plates in a normal position would cease to be operative. Three ratios were used: 0.54, 0.64, and 0.72 (Figs. 89, 90, and 91, respectively). Stockline level is very important, as reference to Fig. 17 will show. Segregation effects due to fall are reversed in direction after impact at the inwall, and quite small changes in stockline level may result in considerable alterations in the distribution pattern.

Similar conditions might easily arise in full-scale practice, if the normal stockline position happened to be situated near the impact level. Slips or abnormal irregularities in charging will completely alter the pattern.

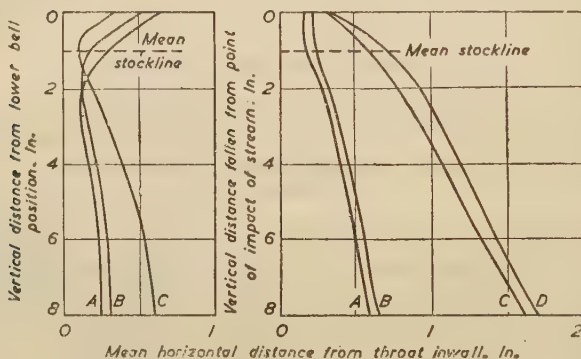


FIG. 17.—Bell/throat ratio: FIG. 18.—Batter angle; A, 0°;
A, 0.54; B, 0.64; C, 0.72. B, 15°; C, 30°; D, 45°.

Figs. 17 and 18.—Variation of Mean Stream Path with Bell/Throat Ratio and Batter Angle.

As such effects may not be felt for some hours, their origin may often be obscure.

(d) *Batter-Angle Variation* (Fig. 18).—Four positions of batter have been selected: 0°, 15°, 30°, and 45° (Figs. 91–94). The difference between 0° and 15° is small, owing to the fact that only part of the stream is intercepted. The next 15° increment towards the centre is such that a change from the V to M contour occurs at this point, as is well illustrated by Fig. 18.

(C) Discharge of a Mixed Burden.

So far we have been dealing with one change at a time and have considered the type of stream associated with each change. In order to investigate what segregation occurs at the moment of discharge of a mixed burden, a series of very short instantaneous exposures was taken to arrest movement, the bell being charged with as intimate a mixture of the constituents as possible and opened to synchronize with the exposure. The top design was maintained constant except for batter angle, which was set either at 0° or 45° to give the inwall and central types of discharge. (Bell

90°, bell drop $\frac{3}{8}$ in., bell/throat 0.72.) Both spherical and irregular-shaped particles were considered.

(1) *Spherical Particles.*

(a) *Size Variation* (Figs. 95 and 96: $\frac{1}{8}$ in. (dark) and $\frac{1}{16}$ in. (light) material; same order of density).—Two points are worthy of note: the larger (coke) particles fall inward towards the centre, and the scatter is greater with the mixed burden.

(b) *Density Variation* (Figs. 97 and 98: $\frac{1}{8}$ in. coke (dark) and $\frac{1}{8}$ in. hematite (light)).—There is, generally speaking, rather more scatter in the case of the lighter coke particles, which also fall more centrally.

(2) *Irregular Particles.*

(a) *Size Variation* (Figs. 99 and 100: 10/20 and 40/60 mesh limestone).—As in 1(a) (above), especially with a batter angle of 0°, the larger particles fall nearer the centre. Scatter is generally increased. From observation there is also evidence of the selective discharge of the fines before the larger materials. (See Figs. 101 and 102 for details of successive stages of the discharge.)

(b) *Density Variation* (Figs. 103 and 104: 10/20 mesh coke (dark) and 10/20 mesh hematite (light)).—The segregation effect is practically nil in the upper part of the model.

Considering all the streaming experiments in general, it would seem that although there is some tendency towards segregation immediately after discharge from the bell, the main factor governing distribution is the particular stockline contour already in existence at the moment of discharge, for on this the behaviour of the particles immediately after impact depends. To study such effects in closer detail further experiments were carried out by discharging the contents of the bell on to a natural stockline resulting from the systematic charge and discharge of the burden.

IV.—SEGREGATION.

(A) *Experimental Procedure.*

The modified form of the "slice-model" (Model 4, Fig. 8b), containing a well of mercury, was employed. Definite volume withdrawals to correspond with bell loadings could then be made. The model was two-thirds filled with neutral material floating on mercury and was then filled to the stockline by successive charges from the bell, which had previously been filled with equal volumes of the selected materials. When the top stockline level was reached, the model was photographed. This gives a general picture of the effect of stockline height upon the distribution. Typical examples are shown in Figs. 105–110.

Alternate additions from the bell and discharges were then made until a throughput of about one-third of the burden had been attained, when the model was photographed again. From the second record, distribution counts were obtained (under a low-power microscope) over a section of the contents immediately beneath the stockline in a locality where changes due to the vertical descent of the burden were known to be slight, thus giving a representative estimate of the extent of segregation.

(B) *Variation in Stockline Height.*

It will be convenient to consider variations in stockline level in conjunction with the following configurations: V, M, and V.* In each case

* This symbol is used to denote the lipped V type of stockline shown in Fig. 116.

graphs have been drawn from particle counts in the corresponding plates at two different levels, $2\frac{1}{4}$ and $4\frac{1}{2}$ in. below the lower bell position (equivalent to 11 ft. 3 in. and 22 ft. 6 in. full scale).

The V type.

Figs. 19 and 105 : 10/20 mesh coke (dark), and 10/20 mesh hematite (light).

Figs. 20 and 106 : 10/20 mesh limestone (dark), and 40/60 mesh limestone (light).

It will be seen in each case how the central chimney narrows as the stockline is raised. This agrees with the variations already noted in

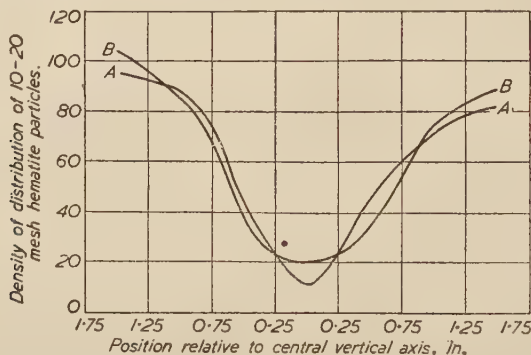


FIG. 19.—Variation of Density Distribution of Irregular Particles with Stockline Level, V-Type Contour. Depth of stockline below lower bell position : A, $2\frac{1}{4}$ in. ; B, $4\frac{1}{2}$ in.

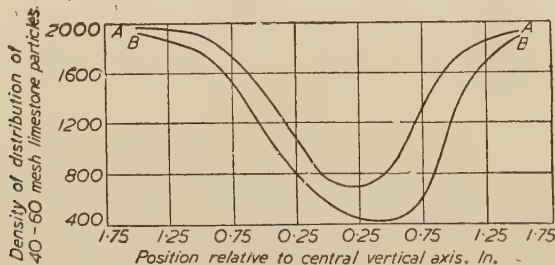


FIG. 20.—Variation of Size Distribution of Irregular Particles with Stockline Level, V-Type Contour. Depth of stockline below lower bell position : A, $2\frac{1}{4}$ in. ; B, $4\frac{1}{2}$ in.

Figs. 47–49, and 51, where the layers become progressively shallower with increasing fall of the burden. (See also the streaming pattern of Fig. 91.)

The M type.

Figs. 21 and 107 : 10/20 mesh coke (dark), and 10/20 mesh hematite (light).

Figs. 22 and 108 : 10/20 mesh limestone (dark), and 40/60 mesh limestone (light).

In the case of the M-shape contour it will be seen that the central chimney broadens as the stockline is raised. (See also Fig. 82.)

The V type.

Fig. 109 : 10/20 mesh limestone (dark), and 40/60 mesh limestone (light).

Fig. 110 : 10/20 mesh coke (dark), and 10/20 mesh hematite (light).

This type of contour is invariably associated with the smaller bell/throat ratio and reference to Figs. 17 and 89 will show that it can only exist at

relatively high levels; in fact a transition point occurs at about 2 in. below the bell. An examination of Figs. 109 and 110 will show that similar changes occur in the distribution. The effect may also be noticed in Figs. 161 and 126 where the coke and 10/20 mesh limestone cease abruptly at the inwalls 5 in. below the bell.

(C) *Segregation in Relation to Furnace Top Design and Burden Characteristics.*

It is now necessary to consider how variations in top design affect the distribution patterns and the segregation of materials in a mixed charge.

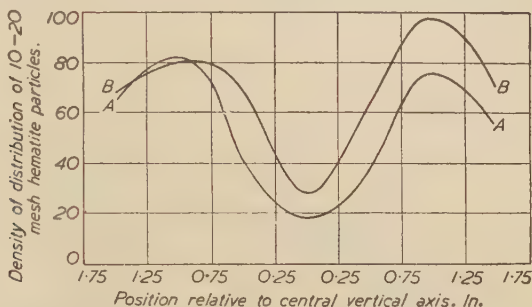


FIG. 21.—Variation of Density Distribution of Irregular Particles with Stockline Level, M-Type Contour. Depth of stockline below lower bell position: A, $2\frac{1}{2}$ in.; B, $4\frac{1}{2}$ in.

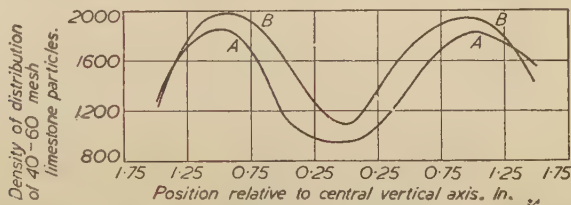


FIG. 22.—Variation of Size Distribution of Irregular Particles with Stockline Level, M-Type Contour. Depth of stockline below lower bell position: A, $2\frac{1}{2}$ in.; B, $4\frac{1}{2}$ in.

There are three divisions relating to the character of materials,

- (1) Materials of different size,
- (2) Materials of different density,
- (3) Materials of different size and density,

each considered in relation to furnace variables and the shape of the materials.

(1) *Size Segregation.*

Materials: (a) *Spherical*: $\frac{1}{8}$ in. coke (dark) and $\frac{1}{16}$ in. tapioca (light).

(b) *Irregular*: 10/20 mesh limestone (dark) and 40/60 mesh limestone (light).

(i) *Variation in Bell Drop* ($\frac{3}{4}$ and $\frac{3}{8}$ in.).

(b) *Irregular* (Figs. 23, 111, and 112).—The contour is of the V type in both cases, with larger particles in the trough. In the case of the larger

drop the V is shallower and segregation tends to be less pronounced than in the smaller one.

(ii) *Variation in Bell/Throat Ratio (0.77 and 0.54).*

(a) *Spherical* (Figs. 24, 113, and 114).—Whilst there is a predominance of coke beneath the trough in both cases, it is not so marked with the

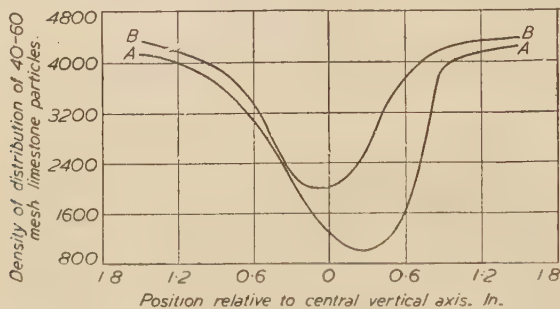


FIG. 23.—Variation of Size Distribution of Irregular Particles with Bell Drop. Bell drop : A, $\frac{3}{8}$ in.; B, $\frac{1}{2}$ in.

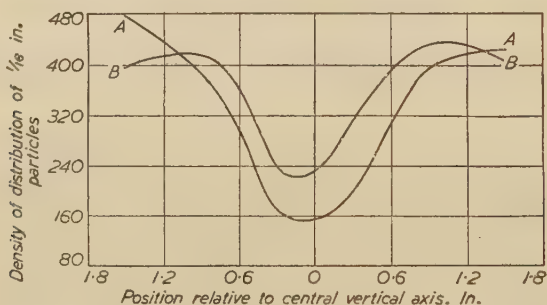


FIG. 24.—Variation of Size Distribution of Spherical Particles with Bell/Throat Ratio. Bell/throat ratio : A, 0.77; B, 0.54.

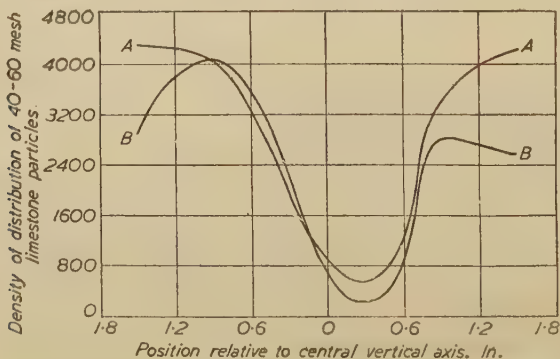


FIG. 25.—Variation of Size Distribution of Irregular Particles with Bell/Throat Ratio. Bell/throat ratio : A, 0.77; B, 0.54.

smaller bell. The number of coke particles at the inwall in the latter case is also higher.

(b) *Irregular* (Figs. 25, 115, and 116).—With the bell/throat ratio at 0.77 the contour is of the V pattern and with the smaller ratio this changes towards the M form. In each case there is segregation of the larger materials in the troughs so that in Fig. 116 the amount of large material at the centre is reduced at the higher levels.

(iii) *Variation in Batter* (0° and 45°).

(a) *Spherical* (Figs. 26, 117, and 118).—The predominance of larger material at the centre is at once evident from Fig. 117, whilst alteration of

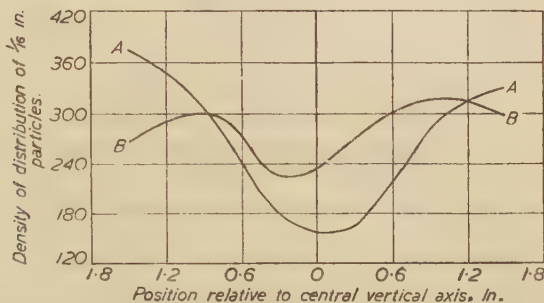


FIG. 26.—Variation of Size Distribution of Spherical Particles with Batter Angle. Batter angle: A, 0° ; B, 45° .

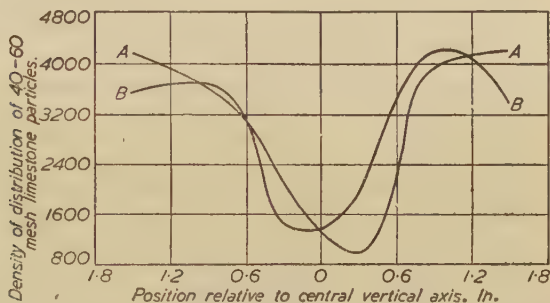


FIG. 27.—Variation of Size Distribution of Irregular Particles with Batter Angle. Batter angle: A, 0° ; B, 45° .

the batter angle to 45° not only results in the usual change of contour from the V to the M form, but also gives a much more uniform distribution.

(b) *Irregular* (Figs. 27, 119, and 120).—Segregation is considerably greater than with spherical particles, especially with the 45° batter, where the central column is still clearly visible and only a little large material is seen at the inwall.

It has already been stated that the smaller particles fall more vertically than large ones. In spite of the fact that the actual difference at the stockline is relatively small, the point of impact of the large material is such that it falls inside the cup of the M and consequently rolls to the centre.

(2) *Density Segregation.*

Materials: (a) *Spherical* : $\frac{1}{8}$ in. coke (dark) and $\frac{1}{8}$ in. hematite (light).

(b) *Irregular* : 10/20 mesh coke (dark) and 10/20 mesh hematite (light).

(i) *Variation in Bell Drop ($\frac{3}{8}$ and $\frac{3}{4}$).*

(b) *Irregular* (Figs. 28, 121, and 122).—The V form is slightly shallower

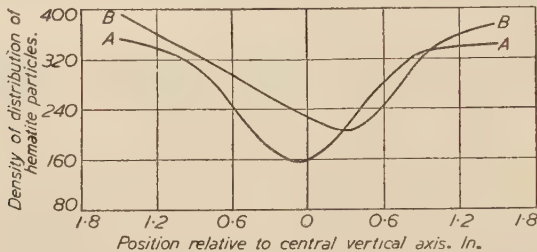


FIG. 28.—Variation of Density Distribution of Irregular Particles with Bell Drop. Bell drop : A, $\frac{3}{8}$ in.; B, $\frac{3}{4}$ in.

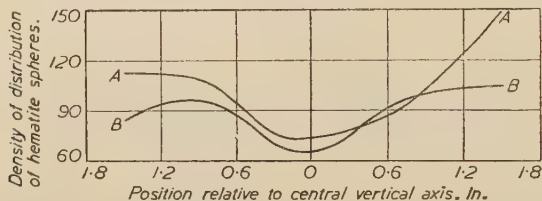


FIG. 29.—Variation of Density Distribution of Spherical Particles with Bell/Throat Ratio. Bell/throat ratio : A, 0.72; B, 0.54.

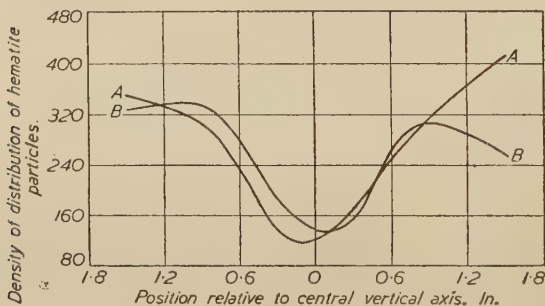


FIG. 30.—Variation of Density Distribution of Irregular Particles with Bell/Throat Ratio. Bell/throat ratio : A, 0.77; B, 0.54.

with the larger drop and the central column less well defined, giving a more uniform distribution.

(ii) *Variation in Bell/Throat Ratio (0.72 and 0.54).*

(a) *Spherical* (Figs. 29, 123, and 124).—The central coke column is discernible in both cases and the change in the stockline contour is only slight.

(b) *Irregular* (Figs. 30, 125, and 126).—The difference in stockline con-

tour is easily seen, and once again the coke predominates beneath the troughs. Segregation is more marked than with spherical material.

(iii) *Variation in Batter (0 and 45°).*

(a) *Spherical* (Figs. 31, 127, and 128).—Coke predominates beneath the troughs.

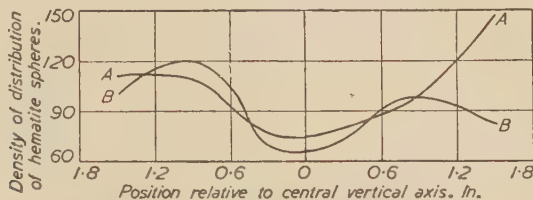


FIG. 31.—Variation of Density Distribution of Spherical Particles with Batter Angle. Batter angle: A, 0°; B, 45°.

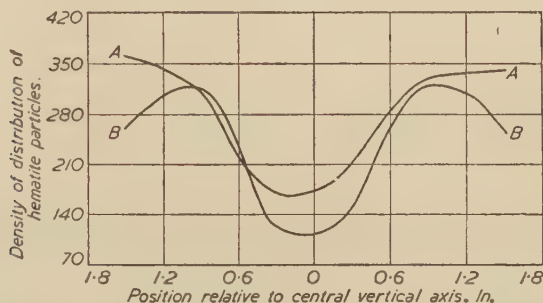


FIG. 32.—Variation of Density Distribution of Irregular Particles with Batter Angle. Batter angle: A, 0°; B, 45°.

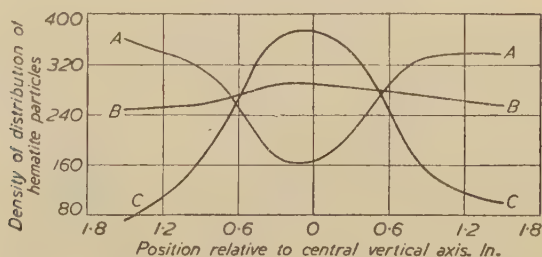


FIG. 33.—Variation of Distribution of Irregular Particles with Size and Density. Density ratio of particles, 3.2. Size ratio of particles: A, 1.0; B, 2.0; C, 4.0.

(b) *Irregular* (Figs. 32, 129, and 130).—The segregation of coke below the trough is considerably more marked than with spherical particles, and in Fig. 130 is in evidence at the inwall.

(3) *Size and Density Segregation* (Fig. 33).

A general case has been chosen with bell angle 90°, bell drop $\frac{3}{8}$ in.,

bell/throat ratio 0.72, batter 0° , and normal stockline. Materials charged as follows :

10/20 mesh coke (dark), 10/20 mesh hematite (light) (Fig. 131).
 20/40 mesh coke (dark), 10/20 mesh hematite (light) (Fig. 132).
 40/60 mesh coke (dark), 10/20 mesh hematite (light) (Fig. 133).

Thus both size and density vary.

Examination of the three photographs and Fig. 33 at once shows how the central disposition of the coke in Fig. 131 gives place to a segregation

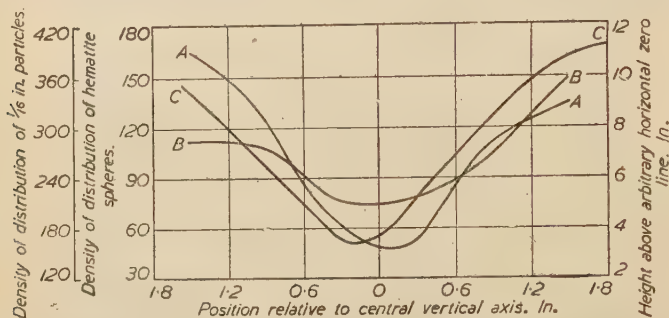


FIG. 34.—Relation between Stockline Contour and Distribution of Spherical Particles; V-type contour. *A*, size distribution; *B*, density distribution; *C*, contour.

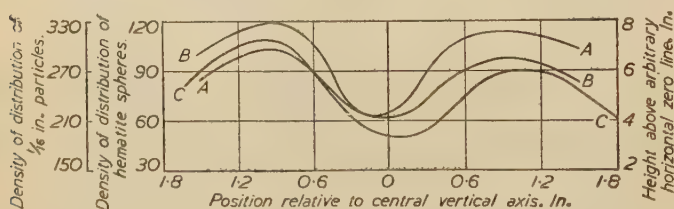


FIG. 35.—Relation between Stockline Contour and Distribution of Spherical Particles; M-type contour. *A*, size distribution; *B*, density distribution; *C*, contour.

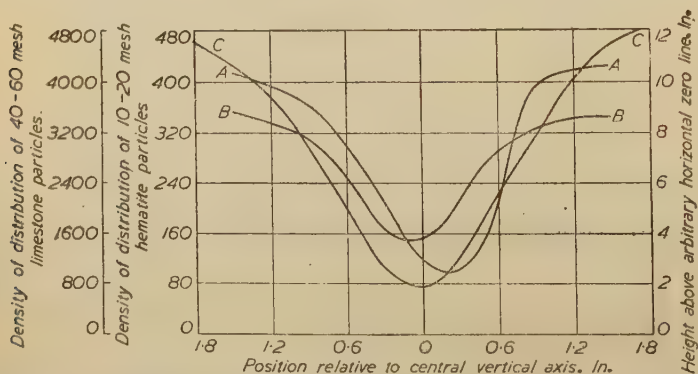


FIG. 36.—Relation between Stockline Contour and Distribution of Irregular Particles; V-type contour. *A*, size distribution; *B*, density distribution; *C*, contour.

reversal in Fig. 133, when the degree of sub-division of the coke is increased from 10/20 to 40/60 mesh. Somewhere in between these extremes, therefore, there will be a transition where the distribution approaches uniformity, and this has practically been realized in Fig. 132. It may be noted that the density ratio of the materials is approximately 3 and the size ratio 2, whereas in Fig. 133 the size and density ratios are about the same, so that size difference produces the greater distributive effect.

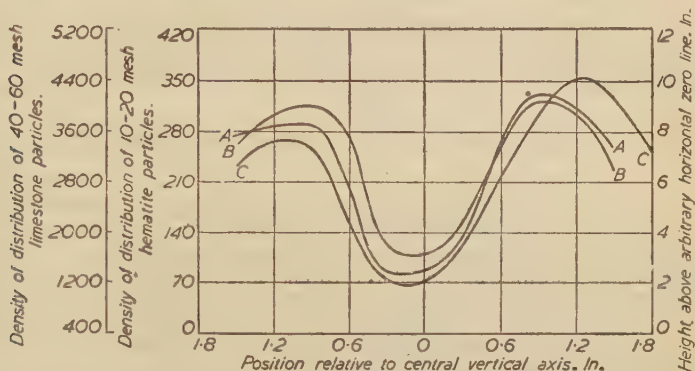


FIG. 37.—Relation between Stockline Contour and Distribution of Irregular Particles; M-type contour. A, size distribution; B, density distribution; C, contour.

In the analysis of all these results mention has been made from time to time of the influence of stockline contour upon distribution. It will be well to consider Figs. 34–37, which have been drawn to illustrate the relation between contour and both size and density distribution for spherical and irregular materials. Figs. 34 and 36 refer to the V type of stockline and Figs. 35 and 37 to the M type. It will at once be evident from the close relationship existing that control of the stockline contour is an all-important factor in the determination of distribution.

V.—CONCLUSIONS.

(1) The streaming experiments show that some distributive effect occurs at the bell orifice, but its influence on the stockline is only small.

(2) Streaming experiments with mixed burdens show that segregation caused by size and density differences is less than might be expected from a consideration of the behaviour of streams of uniform particles, especially when the batter angle is large; the primary effects are in fact masked by multiple impacts. Nevertheless these differences may in certain cases (*e.g.*, M contour) have an important effect.



(3) The stockline contour is one of the main factors controlling distribution.

(4) The behaviour of particles immediately after impact determines to a large extent the nature of the segregation. In general, dense and small materials remain substantially where they fall, thus building up the ridges, whereas light and large materials roll down into the troughs.

(5) The effects under (4) are generally more marked with irregular than with spherical materials, because of increased frictional forces.

(6) Stockline contour is controlled by the following factors in decreasing order of importance: (a) batter angle, (b) bell/throat ratio, (c) bell drop, (d) bell angle.

(7) Size ratio is more important than density ratio in the exercise of segregation control.

(8) Stockline height governs distribution in the following ways as the distance of fall of the burden increases: (a) the M form becomes , (b) the V form becomes V, and (c) the V form becomes —i.e., all become more shallow.

ACKNOWLEDGMENTS.

The experimental work embodied in this paper was carried out at the Imperial College of Science and Technology, South Kensington, for the Blast-Furnace Committee of the British Iron and Steel Industrial Research Council, by whom it was also financed.

APPENDIX: A Note on Scale Effect for Falling Particles in Blast-Furnace Models.

By O. A. SAUNDERS, M.A., D.Sc. (CITY AND GUILDS ENGINEERING DEPARTMENT, SOUTH KENSINGTON).

If air resistance is neglected, there is no scale effect for falling particles, their paths being similar in model and full scale. This follows immediately from the fact that l (linear size), ρ (density), and g (the acceleration due to gravity), which are the independently variable factors, cannot be combined to form a dimensionless group. Moreover, the density of the particles, ρ , has no effect upon their fall.

The velocity at any point, V , is not independently variable, but is determined by l and g in the dimensionless group V^2/lg . Hence $V \propto \sqrt{l}$, i.e., the velocity is proportional to the square root of the linear scale.

It has been assumed, of course, that the model is to scale in every respect. In particular, the height from which the particles drop must be in proportion to the other linear dimensions.

It remains to consider how far these conclusions are true when air resistance is taken into account, and also to consider the effect of an upward air velocity through the model.

(1) Particles Falling Through Still Air.

The variables controlling the fall now include ρ_a (density of air) and μ (viscosity of air), as well as l , ρ , and g , and these may be arranged in the dimensionless groups:

$$\frac{\rho}{\rho_a} \text{ and } \frac{gp^{2/3}}{\mu^2}.$$

Since μ , ρ , and g are all fixed, the value of the group $gp^{2/3}/\mu^2$ is necessarily different for model and full scale, and an unknown scale effect is therefore present as a rule.

The effect of air resistance depends, however, upon the nature of the air flow round the particles, i.e., whether it is streamline or turbulent. Only for very small particles is the flow streamline. In the full-scale applications of the present problem it is certainly turbulent, but in the models the size may not be big enough for fully developed turbulence to exist at the earlier stages of the fall. It is probably fairly safe, however, to regard the flow as turbulent, in which case, since μ (viscosity) has now no direct influence, the group $gp^{2/3}/\mu^2$ may be ignored. The paths in model and full scale are thus similar, provided ρ/ρ_a is the same for both. In other words, the density of the particles now has an effect upon their fall, but since in Dr. H. L. Saunders' models the densities are the same as for full scale, the paths observed by him are exactly similar to the corresponding full-scale phenomena.

It may also be mentioned that the rate of fall would be expected to be slightly more rapid for the denser, and for the bigger, particles. This agrees with the observations already made.

(2) *Particles Falling Through Air having an Upward Velocity, U.*

This case is not fundamentally different from the case of a fall through still air, because only the *relative* velocity between the particle and the air matters (except near the walls of the containing vessel).

Making the assumption of turbulence already discussed, the paths of the particles in model and full scale are similar, provided the upward air velocity, U , is kept proportional to the square root of the linear dimensions of the model.

Thus a velocity of 25 ft./sec. in full scale corresponds to $25/\sqrt{60} = 3.37$ ft./sec. in a $\frac{1}{60}$ th scale model.

(3) *Effects of Surface Friction between Particles, or between Particles and Walls, and of Resilience (where Rebounding Occurs).*

The conclusions arrived at continue to be true when surface friction between the particles, or between the particle and the walls, is taken into account, provided that the coefficient of friction is the same for model and full scale. This condition is satisfied if the same materials are used. Any irregularities of surface of the walls must be reproduced in the model.

The effect of resilience, where bouncing occurs, does not vitiate the conclusions, provided the coefficient of resilience is the same in model and full scale. In addition to using the same material, it might be necessary to support the parts of the walls from which the particles rebound in such a manner that the resilience is similar.

(4) *Effect of Air Temperature.*

If the air temperature is lower in the model than in the full scale, the particle density should be greater, thus keeping constant the ratio (density of particle)/(density of air).

Alternatively, since the effect of varying the particle density has been observed in the models, the effect of slight change in air temperature may be deduced.

Conclusions.

(A) It may be concluded that, provided the models are not on too small a scale, the shapes of the paths of the falling particles will be similar for model and full scale. Where the air has an upward velocity, this must be kept proportional to the square root of the linear scale; *i.e.*, 25 ft./sec. at full scale corresponds to 3.37 ft./sec. at $\frac{1}{60}$ th scale.

(B) Within the accuracy of the measurements made by Dr. H. I. Saunders, it seems likely that his models are big enough to be free from the objection referred to in (A) above.

Any small differences which may occur for this reason would appear in the early part of the fall, soon after the particles leave the bell. If it is thought desirable to make sure that any such effects are negligible, this could be done by constructing a specimen model of, say, $\frac{1}{20}$ th scale, and comparing it with the $\frac{1}{60}$ th scale model.

(C) Surface friction and rebound effects do not vitiate the conclusions so long as the same materials are used in model and full scale, and care is taken to reproduce any irregularities in the wall surface.

(D) Summing up, there appears to be no need for extensive larger-scale models in the present problem, since these would only give similar results to the present ones. Much depends, however, on the accuracy required; if a considerable degree of accuracy is wanted, it might be worth constructing a special $\frac{1}{20}$ th scale model, in order to verify that the objection mentioned in (B) above has only negligible effect.

DISCUSSION.

During the presentation of the paper, Dr. SAUNDERS showed a cinematograph film to illustrate some of the things which happen inside a blast-furnace.

First of all the derivations of the two main types of stockline (V and M) and their associated segregation—fines on the hills and lumps in the valleys—were seen. It was pointed out that, under blast, the major flow is almost entirely through the larger material, even when the segregation has been artificially controlled to give an extreme pattern. A normal slip pattern was shown, followed by the directional effect of the slip planes on the blast. The remainder of the film consisted of a series of shots of mainly undesirable happenings inside the blast-furnace, due to blast irregularities originating from poor or unequal distribution of the fines or from the presence of moisture.

Finally, the ideal case was shown—adequate and even blast flow at a reasonable pressure, without undue movement of the burden.

Mr. C. A. J. BEHRENDT (Hon. Member of Council) (Appleby-Frodingham Steel Co., Ltd., Scunthorpe): I am filled with admiration for the ingenuity and the thoroughness of the way in which the authors have tackled this problem, but I must confess that I am a little hazy in my mind as to the practical application of their work, and I hope that they will be able by the breeze of common sense to blow away the fog of doubt which exists in my mind. I am sure that all blast-furnace men fully realize the importance of the distribution of materials on to, and therefore into, the furnace stock column, but I am not sure even now that I know what I would lay down as correct distribution. All that I do know for certain is that we must not have an agglomeration of fines at the furnace walls. I am sure of that, and we are experimenting on those lines to get the annulus of fines away from the furnace walls.

The authors have provided us with an excellent and exhaustive study of distribution and the flow lines as it proceeds down the stack, and I suppose it now lies with us to make practical application of the data which they have provided. The filling on to the stockline and the stockline contour obtained seem to me to be reasonably easy of attainment by means of bell size and angle, throat design, and so on, but I am not at all convinced about what occurs when some of our materials start on their rake's progress down the stack. We are fairly convinced, I think, that there is a persistency through the stock column which is more or less effective from stockline to bosh. As the materials are put in at the top, there is a persistency right down to the bosh. This I accept and admit, but the mechanics of it are a little obscure to me; and the authors' flow lines, which have necessarily been determined on materials which suffer no change on their downward passage, do not seem to me quite to fill the bill.

What of the ores that we use in our North Lincolnshire practice? We

can charge our ore, or at least some of it, in nice pieces, as shapely as cricket balls, but after a comparatively few feet of travel downwards each cricket ball becomes half a dozen badly used golf balls, and before it gets midway down the stack it is probably more like half a bucketful of hen-food. Surely that must have altered the distribution enormously? The flow lines must have been seriously affected by the physical changes which have taken place, and the original distribution altered and distorted to no small degree, and all this before we have got half-way down the stack.

The coke is, in my view, the only component of our stock column that remains reasonably stable from a physical point of view, and even that by fracture and abrasion must alter fairly seriously. Even if we indulged in what has been something of an ideal with me for a long time, and charged our materials in a greater range of separated size fractions, I am afraid we should still find that the authors' nice, orderly flow lines became thoroughly disturbed and distorted at an early stage.

Moreover, there is one factor here which I cannot refrain from mentioning, and that is that although we charge our ores—and for that matter our coke too—in a mixture of sizes, from, say, 4 in. down to $\frac{1}{2}$ in., however much we have played with other charging sequences I should say that we inevitably revert to intimate mixing of coke and ores. We have tried layer charging, thick layers, thin layers, stratification and so on, but we always come back in the end to an intimately mixed charge. It seems to me that it is logical to assume that the smaller the particle the more rapidly it is affected by heat and gas action, with the result that there is apt to be a very heterogeneous mass in various levels and in various annuli in the stock column, which would upset any theory of orderly flow.

It does really seem to me that, having succeeded in obtaining the stockline contour which we require, or think we require, then beyond slight modifications of manipulation to effect temporary changes which we may find desirable from time to time, the rest of the descent of the stock is outside our control.

I seem to have gone a very long way round in order to reach the question which I want to put to the authors, and which is this: Do they think that experiments with the materials which they have used, which are subject to no change on their downward path, can give at any time a representation of the movement of materials which are constantly altering physically in the furnace? Is not the contour of the stockline the one and only thing over which we have a reasonable chance of establishing control?

Sir ALFRED EGERTON, F.R.S. (Imperial College of Science and Technology, London): I have been very interested to see the film which Dr. Saunders has shown, which gives a very interesting portrayal of a fine piece of work on the question of distribution which the authors have carried out. I am very proud to have this work going on in our laboratory, but I am afraid that, as often happens, I leave what is going well to go well, and I know that under Dr. Saunders' direction it is in very good hands.

Distribution is, I am sure everyone will agree, very important in many directions. It is one of the most important problems in almost all subjects; whether we are dealing with population or with industry or with wealth, it is always a question of over-concentration in one place which creates difficulties. That is true even in the ballroom!

The only way in which science can contribute to progress—and I think everyone will agree that progress is fairly rapid, and in fact almost

too rapid, at the present time—is by a process of breaking up the problem into its primary factors, each of which it can deal with alone, and then seeing how to put the picture together afterwards. I feel that the work which the authors have done has been in accordance with the true principles of the methods of science, and will therefore help in dealing with any problems of distribution in the blast-furnace.

Mr. Behrendt thought that this work might be too far removed from practice, but when we know what the different sizes of particle do in different parts of the furnace, it is possible to put the picture together afterwards. Of course, the question of what happens at high temperatures is another matter, although a good deal of deduction is possible from the experiments carried out at low temperatures as to what will be the behaviour at high temperatures. We hope, however, to be able to test what is happening when the changes are occurring in a furnace by means of the experimental blast-furnace which is being put up at the present time. Already the small, one-eighth scale furnace which has been experimented with shows promise of making it possible to obtain very useful results from work in that direction. I feel that it is very important not to try to go to a very large scale, because this always involves great difficulties. Even though later on it may be necessary to test certain points on a larger scale, small-scale work is of very great importance, and is the only method by which it is possible to make real advance, apart from a lucky shot.

I should like to congratulate those who have been working on this subject, and Dr. Saunders for his presentation of it to-day. We who work in universities and in technical colleges are very anxious to be in as close touch with industry as possible and to make ourselves as useful as possible to industry, and for that purpose we look forward to working on problems which are of importance to industry, because it is by that close touch that we can formulate the problems and use our resources to solve them.

Dr. L. REEVE (Appleby-Frodingham Steel Co., Ltd., Scunthorpe) : This is the second time that I have had the pleasure of seeing this film; I saw it two years ago, when it was still on the secret list. There was one point which struck me then and which has struck me again to-day rather more forcibly. I do not know whether the authors can give any explanation of it. In a way, it is the same point that Mr. Behrendt has made, and concerns a confusion of thought on the subject of persistence of stock running and persistence of distribution. I think that we have to take persistence as absolutely proved by the work on gas analysis and temperature distribution of the Americans and also of Dr. Stacey Ward at Appleby-Frodingham. But, apart from Mr. Behrendt's point, the film showed a curious thing on which Dr. Saunders did not comment : when he was blowing the blast, the persistence of his stockline, except when his distribution was perfect, was a matter of seconds; it broke up completely, and left, right, and centre were all mixed up. I should like the authors to tell us whether the conditions of blowing, when the blast was going at what appeared to be a very great rate, were in line with the size of the model.

Another reason for asking that question is that in the other types of distribution, where he blew chlorinated air through his model, the rate of flow was extremely slow. Was that due to the diffusion of chlorine, or was that the actual rate of flow of his blast? In the latter case, which was the scale model of the rate of flow? Was it the low rate of flow with chlorinated air, or the apparently high rate of flow which the authors got with their high blast pressure?

Mr. R. P. TOWNDROW (Cargo Fleet Iron Co., Ltd., Middlesbrough) : Sir Alfred Egerton said that when something is going well he likes to leave it alone. I think that that is true of no man more than the blast-furnace manager. He is so highly delighted when his furnace works properly for a little while that he does not like to interfere with it more than is necessary; it is when the furnace is showing signs of trouble that he finds himself most in need of all the help that science can give him. We must congratulate Dr. Saunders and his colleagues heartily on giving us a very powerful weapon of diagnosis to give us a lead on some of the problems which beset us in day-to-day furnace operation. I think that it is immaterial whether this method gives us an exact picture. Indeed, the authors will not claim that it does; in some of the pictures the conditions were, I imagine, deliberately exaggerated in order to bring out certain points. But the picture does show us the tendencies which we may expect, and that is what the practical man wants to know; he wants to know what is the most likely thing that can happen in his furnace under a given set of conditions, and I think that both the catalogue of pictures giving different sets of conditions and the film have provided us with a most powerful tool, if only as a stimulus to our imagination to help us to realize what can happen in the furnace. We should all be grateful to the authors for this work.

Mr. R. SHARP (Stanton Iron Co., Ltd., near Nottingham) : There is one point which I think it would be well to make with regard to these experiments of Dr. Saunders and his associates, and that is that all the experiments are on a model fitted with the bell and hopper. The bell and hopper was invented by Parry of Ebbw Vale in 1860, and after 85 years is still the means of loading a blast-furnace. These experiments prove, and our whole life experience proves, that the bell and hopper creates segregation in the furnace; what I should like to see, and what I have been thinking about for very many years, is some other form of charging the furnace which does not create segregation.

I remember, when I was quite a youth, seeing sketches of different forms of bell construction which did not consist of just a bell and hopper but of annular rings arranged to give in the furnace four lines of segregation, an M-formation repeated four times. If you get that, you cannot get the segregation which is shown in the authors' model. I have also felt that some other device could be thought out whereby the charging skip would not deliver on to the top of the furnace at all but into hoppers at the side of the furnace; then a charging car could come under these hoppers and get its load perfectly evenly distributed, and then go over the top of the furnace through a gas seal and be lowered into the furnace, thus giving an even distribution over the furnace top.

From the point of view of the blast-furnace manager and the blast-furnace engineer there is no chance of experiments of this sort ever being put into operation in practice; the capital which would be involved and the risk which would have to be taken are things that nobody would care to face just now, or probably at any time; but if on an experimental furnace of reasonable size something of that kind could be proved to be helpful, we might get a full-size furnace equipped in that way.

I am sure that is the solution; and, although we are very pleased to have the help of Dr. Saunders and his colleagues in finding out what are the troubles experienced in the furnace owing to the segregation caused by the bell and hopper, it does not seem to me to be very practical to continue for all time working with an apparatus which will always create these segregations.

AUTHORS' REPLY.

The AUTHORS wrote in reply : There are, of course, limitations in this experimental work ; Mr. Behrendt referred to this, and so did Dr. Reeve. Mr. Behrendt mentioned changes in the materials as they go down the furnace. The burden will vary in size and nature from one level to another ; there will be sintering, slag formation and so on. We do not yet know the whole story of all the changes which occur between the stockline and hearth, but the matter is under consideration and we hope to present additional information in the not too distant future.

Mr. Behrendt asks what is the ideal distribution in the furnace. We think that is something for the blast-furnace manager to specify. Everybody will have his own ideas, but if we know what they are we will tell you the easiest way to attain your object.

With regard to Dr. Reeve's question, the cases to which he refers were extremes. On the one hand there was deliberate overblowing, and on the other the slow-motion chlorine pictures were made at a suitable rate for detailed study. The correctly scaled blast would be intermediate, and except where channelling prevailed would not necessarily introduce so much disturbance in the burden. We are, however, able to reproduce phenomena which are known to occur in practice. We have studied the conditions which initiate them. We have shown them in the film with the object of assisting the operator to elucidate some of his difficulties.

Reference was made to special methods of charging. There is no reason why the bell and hopper should be retained in precisely the same form as now. Something might be done on the following lines : Leaving out the auxiliary gas seal, which might remain much as before, suppose the bell, instead of overhanging, were made just small enough to pass through the hopper orifice ; dropping it in the normal way would give a V type of stockline contour ; raising it will give an inverted V. Thus, the distribution patterns would be complementary, and by a suitable arrangement of the cycle any degree of compensation could be effected.

A RAPID METHOD OF ORE TESTING. THE "S.K." POROSITY TEST.*

By H. L. SAUNDERS, PH.D., F.R.I.C., AND H. J. TRESS, PH.D. (IMPERIAL COLLEGE, SOUTH KENSINGTON).

SYNOPSIS.

An apparatus is described for the rapid determination of the porosity of ores by what is known as the "S.K." (South Kensington) test. The principle of the test is to fill the voids in turn with mercury, air, and water; for porous materials the voids are greatest for air, less for water, and least for mercury. The differences between the values are a measure of the porosity relative to the fluids employed. Several specimens of ore and sinter were examined. Ores are more porous than sinters, while the voids of mixtures are additive. It is shown how the measurements can be applied to forecast the behaviour of materials in the blast furnace (deoxidation and carbon deposition).

Introduction.

DETAILS of ore test methods have already been described in considerable detail in Part III. of the series of papers: "An Experimental Enquiry into the Interactions of Gases and Ores in the Blast Furnace."† These methods, though capable of giving much valuable information about the behaviour of an ore under specific conditions, are somewhat lengthy and need special apparatus and a skilled technician if full value is to be derived from them.

Under conditions of restricted supply of raw materials, day-to-day changes in blast-furnace burdening may be necessary, and it was felt that some quicker method, *e.g.* by evaluating porosity, even though less fundamental, would be more useful, so the "S.K." (South Kensington) test was devised. Relatively simple apparatus is required, and once the principle has been grasped the actual tests may be quickly carried out. Quantitative measurements of reduction rates (within specified limits of CO_2 concentrations in the reducing gases at varying degrees of reduction for definite times of contact) are not sought. Instead, the reduction process is treated generally. The chemical changes involved in the reduction of an ore to metallic iron are for the most part similar in character, even though the initial composition may vary considerably, so that physical characteristics must play an important rôle in determining reducibility; among these, diffusion of the gases into the interstices of the ore is perhaps the greatest, for all chemical reactions depend upon the ability of the reactant to come into contact. When the reaction velocities are high it may well be that the rate of gaseous diffusion is the slowest in the chain and therefore the factor governing the whole sequence of changes. A lump of ore, say 250 g., having a superficial area of some 250 sq. cm., may, broken down to $\frac{1}{4}$ - $\frac{1}{10}$ in. mesh, have a total surface of 3000 sq. cm.; but if the total porosity of these same particles be considered (assuming capillaries of an average size of 0.01 mm.), the total surface then exposed will certainly exceed 500,000 sq. cm. Hence a physical characteristic like porosity can be used as an index to assess the quality of a particular ore; although it should always

* Received March 13, 1945.

† *Journal of The Iron and Steel Institute*, 1934, No. I., pp. 33-46.

be remembered that the composition of the material must be continually borne in mind, even when compensation for iron content is introduced.

Direct measurements of diffusion rates through segments of ore were first attempted, but the technique could not be sufficiently simplified for general works use, and eventually it was decided to substitute the measurement of porosity with a convenient form of apparatus. Porosity, as an indirect measure of the available surface open to gaseous attack, gives interesting information on the true meaning of texture. By immersing lumps of the selected material in various fluids, and measuring the amount of fluid penetrating the solid, a range of porosities may be derived, and by the use of suitable media some idea of the relative pore-size distribution may be determined. The pores measured will include all cavities connected with the voids by accessible channels, but will not include those which are completely sealed. It therefore gives a more valuable assessment of the extent of the surface open to attack than methods based on powder density.

Theory of the Method.

The permeability figure determined by different fluids was generally found to increase in the following order: mercury *in vacuo*, followed by mercury, water, and air at atmospheric pressure.

If the solid and a particular fluid, f , fill a standard volume, A , then:

$$V_f + S_f = A \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where V_f = volume of fluid displaced by the solid, and S_f = volume of fluid filling the rest of the standard volume.

Let $\Delta V_{f_1/f_2}$, defined as the f_1/f_2 porosity, be the volume of solid penetrated at atmospheric pressure by fluid f_1 , but not by fluid f_2 ; then from equation (1):

$$\Delta V_{f_1/f_2} = V_{f_1} - V_{f_2} = S_{f_2} - S_{f_1} \quad . \quad . \quad . \quad . \quad (2)$$

where the subscripts f_1 , f_2 , unless otherwise stated, refer to fluids under atmospheric pressure.

Let ΔV_p , defined as the pressure porosity, be the volume of mercury entering the solid when the pressure at the surface is increased from zero to one atmosphere; then:

$$\Delta V_p = \frac{V_{\text{Hg(vac.)}} - V_{\text{Hg}}}{S_{\text{Hg}} - S_{\text{Hg(vac.)}}} \quad . \quad . \quad . \quad . \quad (3)$$

S , the amount of fluid entering the standard volume, is easily measured, so that by using equations (2) and (3) the following porosities—ranging from coarse to fine—can be determined:

$$\Delta V_p = \frac{V_{\text{Hg(vac.)}} - V_{\text{Hg}}}{\text{Volume of pores entered by mercury at atmospheric pressure but not in a vacuum.}} = S_{\text{Hg}} - S_{\text{Hg(vac.)}}$$

$$\Delta V_{\text{H}_2\text{O/Hg}} = \frac{V_{\text{Hg}} - V_{\text{H}_2\text{O}}}{\text{Volume of pores entered at atmospheric pressure by water but not by mercury.}} = S_{\text{H}_2\text{O}} - S_{\text{Hg}}$$

$$\Delta V_{\text{air/H}_2\text{O}} = \frac{V_{\text{H}_2\text{O}} - V_{\text{air}}}{\text{Volume of pores entered at atmospheric pressure by air but not by water.}} = S_{\text{air}} - S_{\text{H}_2\text{O}}$$

Apparatus.

The "S.K." test apparatus is shown diagrammatically in Fig. 1. C is a container with a main bulb of about 105 ml. capacity, fitted at the base with a tap T_5 and capillary stem, the top carrying a ground joint sur-

mounted by a bulb (10 ml.) and tap T_4 . D is a burette graduated in tenths from 0 to 100 ml., with two bulbs and a 3-way tap T_2 at the lower end. E is a water reservoir with a tap T_3 , a bulb of about 110 ml. and a stem graduated from 0 to 30 ml., terminating in a small funnel. G is a mercury reservoir. F consists of two bulbs (160 ml. and 30 ml. respectively) fitted to a T-piece. D , F , and E are normally situated at progressively lower levels. H is a vacuum manometer and K one of the differential oil type. Provision is made by way of tap T_1 for connection to a Hyvac pump or

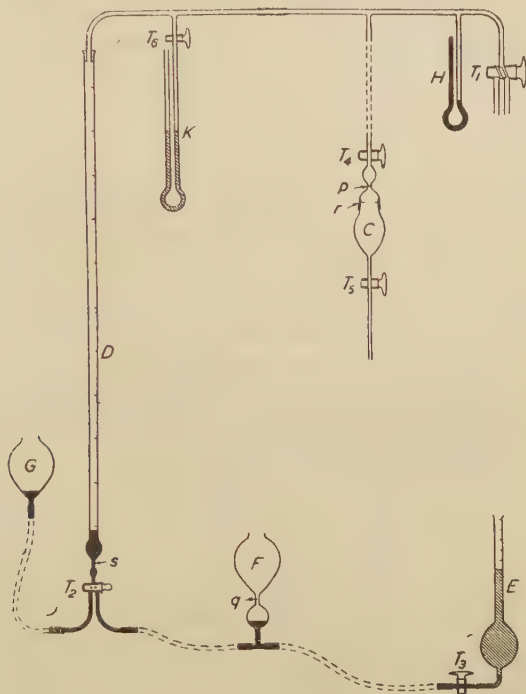


FIG. 1.—Apparatus for S.K. Porosity Test.

to dry air. (A filter pump is inadequate.) There are reference marks p , q , r (etched internally), and s . Connections are made with rubber pressure tubing. It is advisable to maintain the individual position of the various components of the apparatus to eliminate differences of pressure in the rubber connections. Distilled mercury and gas-free water must be used.

Let the volume of container between mark p and the bottom of the stem of tap $T_5 = A$ (corresponding to A in equation (1) above), and the volume between mark r and top of stem of tap $T_5 = B$, which is the volume in which the material will be contained and is conveniently made 100 ml. for direct percentage readings.

Experimental Procedure.

It is first of all necessary to determine (1) the weight of material W , (2) the volume $S_{\text{Hg(vac.)}}$, and (3) the volume S_{Hg} .

(1) *W*.—The material is crushed and sieved to 4–10 mesh and dried at 120–130° C. The dry weighed container *C* is filled to the mark *r* (after standard tapping) and reweighed. The increase = *W*.

(2) $S_{\text{Hg(vac.)}}$.—Fill the charged container *C* with mercury under vacuum as follows:

(a) Connect *C* to the apparatus and by suitably manipulating reservoirs and taps bring the mercury to the top of *D*, the mark *q*, and the bulb side of tap T_3 , care being taken to eliminate trapped air. Close all taps except T_1 , which is turned to air.

(b) Read *D* ($= X_1$).

(c) Run mercury from *D* to *F*, using the suction to fill the stem of *C* above T_5 , which latter is then closed. Open T_1 to air and when the levels in *D* and *F* are nearly the same close T_2 .

(d) Exhaust *C* for 10 min. *via* T_1 .

(e) Fill *C* to mark *p* with mercury *via* T_5 (2 min.); *C* is now full to the mark *p* under vacuum; close T_4 .

(f) Run mercury above mark *q* back to *D* *via* T_2 ; turn T_1 to air.

(g) Read *D* ($= X_2$). Then $S_{\text{Hg(vac.)}} = X_2 - X_1$.

(3) S_{Hg} (*i.e.*, *S* at atmospheric pressure).—*C* is filled to *p* with mercury at atmospheric pressure as follows:

(a) Run mercury from *D* to *F*. Open T_5 until mercury reaches T_4 ; close T_5 .

(b) Open T_1 to Hyvac pump and transfer mercury from *F* to *D* until the lower bulb of *F* is less than half full; close T_2 and turn T_1 to air.

(c) Open T_4 and run out mercury above *p* *via* T_5 . *C* is now full to the mark *p* at atmospheric pressure.

(d) Run mercury from *D* to *F* to the mark *q*.

(e) Read *D* ($= X_3$). Then $S_{\text{Hg}} = X_3 - X_1$.

From the foregoing three sections the following equations are derived:

$$\text{Mercury voids,} \quad V_{\text{Hg}} = A - S_{\text{Hg}} \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (4)$$

$$\text{Density,} \quad \text{Voids}_{\text{Hg}} = B - V_{\text{Hg}} \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (5)$$

$$\text{Pressure porosity,} \quad \frac{\rho_{\text{Hg}}}{\Delta V_p} = W/V_{\text{Hg}} \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (6)$$

$$\Delta V_p = \frac{S_{\text{Hg}}}{X_3 - X_2} - \frac{S_{\text{Hg(vac.)}}}{X_2 - X_1} \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (7)$$

Next follows the determination of the air/mercury ($\Delta V_{\text{air/Hg}}$) and water/mercury ($\Delta V_{\text{H}_2\text{O/Hg}}$) porosities.

(4) $\Delta V_{\text{air/Hg}}$.—The immersion fluid is now changed to air, the volume of which will generally be in excess of the previous volume of mercury. This is accomplished as follows:

(a) Transfer mercury in *D* above the mark *s* to the reservoir *G* and open T_6 .

(b) Close T_1 , thus confining a fixed volume of air at atmospheric pressure. (Temperature should be kept constant throughout the following operations.)

(c) Run the mercury out of *C* *via* the tap T_5 (2 min.), maintaining approximately atmospheric pressure (manometer *K*) by running mercury from *G* to *D*. After 10 min., finally level *K* and close T_6 .

(d) Read *D* ($= X_4$).

(e) Run mercury above *s* from *D* to *G*.

(f) By turning T_1 to vacuum, transfer mercury above *q* from *F* to *D*, finishing with T_1 turned to air.

(g) Read *D* ($= X_5$).

Then

$$\Delta V_{\text{air/Hg}} = X_5 - X_4.$$

(5) $\Delta V_{\text{H}_2\text{O}/\text{Hg}}$.—The immersion fluid is now changed to water, the volume being generally less than that of the air.

- (a) Read water level in E ($= X_6$).
- (b) Open T_5 and drain remaining mercury into F .
- (c) Wet the outside of the stem below T_5 before immersing it in E .
- (d) Run mercury above s (still at X_5) from D to F , utilizing this pressure fall to fill the stem with water to T_5 thus: close T_1 , open T_2 to F , close T_5 , open T_1 to air, close T_2 .
- (e) Exhaust C (8 min.) via T_1 ; close T_4 and turn T_1 to air.
- (f) Operate T_5 and T_3 simultaneously so that sufficient water is always present to cover the stem below T_5 . Close T_5 when the water reaches T_4 (1 min.) and close T_3 after bringing the mercury to q ; open T_4 .
- (g) 15 min. after entry run out the water above p . Remove C .
- (h) Read E ($= X_7$).

Then $\Delta V_{\text{H}_2\text{O}/\text{Hg}} = X_7 - X_6$.

The air/water porosity is obtained by difference:

$$\begin{aligned}\Delta V_{\text{air}/\text{H}_2\text{O}} &= V_{\text{H}_2\text{O}} - V_{\text{air}} \\ &= (V_{\text{Hg}} - V_{\text{air}}) - (V_{\text{Hg}} - V_{\text{H}_2\text{O}}) \\ &= \Delta V_{\text{air}/\text{Hg}} - \Delta V_{\text{H}_2\text{O}/\text{Hg}}.\end{aligned}$$

The method may be shortened should it be desired to ascertain the density or voids only, or alternatively a limited range of porosity measurements.

Certain time limits are specified, but variations within $\pm 10\%$ do not affect the reproducibility of the results.

The size and shape of the container should be standardized as far as possible. This applies particularly to the determination of $S_{\text{Hg}(\text{vac.})}$ (and consequently ΔV_p), which depends upon the depth of immersion of the material.

Disturbance of the voids caused by the upthrust of the mercury and also the dependence of V_{Hg} upon the barometric pressure have been found to have negligible effect.

After immersion in mercury the few droplets which generally remain trapped in the material may introduce a slight error, despite the fact that their actual volume is allowed for in the standard technique, which employs differential measurements. If greater accuracy is required, retained mercury may be eliminated by a somewhat longer procedure where two experiments are performed with separate samples for (a) S_{air} and S_{Hg} and (b) S_{air} and S_{water} .

After thorough evacuation and immersion in a fluid, the attainment of true equilibrium may take a considerable time, but the initial stages are so rapid that the times specified are adequate. This appears to be a general phenomenon, other fluids, e.g. dekaline, showing a parallel behaviour to water. Nevertheless hydration may introduce an error with materials such as sinters of high free-lime content, but generally this is not sufficient to warrant the substitution of a special medium for water.

The above considerations should be kept in mind if rapidity of operation is not the primary concern.

Porosity Results.

There are two ways of expressing the results: (a) $V + \text{voids} = 100$, corresponding with the usual technical practice, for which the apparatus gives results directly in terms of percentages if B (the volume in which the material is contained) = 100 ml.; and (b) $V_{\text{Hg}} = 100$, which is the more accurate and scientific expression, because any uncertainty due to packing in the value of the voids is reflected in the voids measurement only, instead

TABLE I.—*Porosity Determinations*

No.	Description of Ores and Sinters.	Deoxi- dation, % ⁺ ₊	ρ_{Hg} , g./ml.	V_{Hg} .		Voids.	
						$\text{Hg}(\text{vac.})$.	
				a ,*	b ,†	a ,*	b ,†
<i>Home Ores :</i>							
1	West Coast Hematite . . . . .	...	3.96	52.5	100	...	...
2	Lincolnshire (I.) . . . . .	...	2.24	48.5	100	...	...
3	Lincolnshire (II.), top of bed . . . . .	...	2.45	49.2	100	...	...
4	" " middle of bed . . . . .	...	2.42	49.1	100	...	...
5	" " bottom of bed . . . . .	...	2.47	49.1	100	...	...
6	Cleveland (green) . . . . .	...	2.35	48.3	100	...	...
7	Blackband . . . . .	...	1.92	48.2	100	...	...
8	" , heated to 800° C. in absence of air	41	1.90	45.5	100	52.0	114.5
<i>Foreign Ores :</i>							
9	Spanish Rubio . . . . .	...	3.00	50.0	100	48.2	96.4
10	Shenango Purple	} American	2.17	57.6	100	...	...
11	Mesabi Orange		3.52	44.1	100	...	...
12	Shenango Yellow		2.03	53.4	100	...	...
13	Corsica		3.76	43.5	100	...	...
14	Spaulding		3.40	49.3	100	...	...
15	Raimund . . . . .	...	3.07	46.3	100	...	...
<i>Sinters :</i>							
16	North-East Coast . . . . .	...	3.28	36.2	100	62.3	172
17	Scotland	8	3.52	36.9	100	60.2	163
18	Purple ore 40, Northants 30, mill scale 10, fine dust 20%. Pan	17	4.26	42	100	56.7	135
19	Lincs. 47, dried Northants 14, fine dust 18, returned fines 17, coke 4%. Pan	11	3.51	34.6	100	59.2	150
20	Ore 70, fine dust 20, mill scale 5, coke 5%. Travelling grate	8	3.41	34.4	100	64.1	186
21	Benisaf 67, fine dust 6, borings 10, Dorr sludge 17%. Travelling grate	10	4.26	38.2	100	61.0	160
22	Selected sample . . . . .	...	3.59	35.8	100	60.6	169
23	Fine dust 34, pyrites 22, scale 12, spathic 7, returned fines 21, coke 5%. Pan	15	4.30	42.5	100	56.2	133
24	Agglomerates (fine dust 65, pyrites 35%). Rotary kiln . . . . .	...	4.17	40.7	100	...	...
25	Blackband calcined to give sinters of different textures	25	4.26	39.4	100	58.8	150
26		20	4.35	41.0	100	56.8	129
27		...	4.61	34.6	100	...	...
28		...	4.20	42.1	100	...	...
29		...	4.35	47.2	100	...	...
30	Reactive carbon (10-20 mesh) to illustrate sorption . . . . .	...	1.09	55.1	100	...	...

* a = calculated on the basis $V + \text{voids} = 100$.† b = calculated on the basis $V_{\text{Hg}} = 100$.

of in all the values calculated on the technical basis. Results are shown in Table I, calculated on each basis and lettered accordingly; some are graphed in Fig. 2.

It will be seen that $V_{\text{Hg}(\text{vac.})} > V_{\text{Hg}} > V_{\text{H}_2\text{O}} > V_{\text{air}}$; or $\text{Voids}_{\text{Hg}(\text{vac.})} < \text{Voids}_{\text{Hg}} < \text{Voids}_{\text{H}_2\text{O}} < \text{Voids}_{\text{air}}$, and also that the mercury voids for ores are less than for sinters, though owing to the greater porosity of ores the air voids are roughly the same in both cases. Air voids considered alone really depend on size grading and packing; for the 4-10 mesh material in this apparatus the value is approximately 65% ($V + \text{voids} = 100$). In two cases the presence of active carbon manifests itself by superimposing marked sorption on the air voids, thus giving abnormally high figures (Nos. 8 and 30) and this is often a useful guide to the enhanced reactivity to be expected from such material. With regard to sinters, although these are made from such a wide variety of different materials their voids and porosity figures show surprisingly little variation among themselves.

by the S.K. Method.

Voids.						ΔV .									
Hg.		H ₂ O.		Air.		p.		Air/Hg.		H ₂ O/Hg.		Air/H ₂ O.			
a.*	b.†	a.*	b.†	a.*	b.†	a.*	b.†	a.*	b.†	a.*	b.†	a.*	b.†	a.*	b.†
47.5	90	54.4	103	56.9	108	...	...	9.4	17.8	6.9	13.0	2.5	4.8		
51.5	106	64.0	132	69.2	143	...	...	17.7	36.5	12.5	25.8	5.2	10.7		
50.8	103	63.1	128	68.9	140	...	...	18.1	36.7	12.3	25.0	5.8	11.7		
50.9	104	59.7	122	63.4	129	...	...	12.5	25.5	8.8	18.0	3.7	7.5		
50.9	104	58.4	119	60.5	123	...	...	9.6	19.5	7.5	15.2	2.1	4.3		
51.7	107	66.4	137	67.9	140	...	...	15.9	32.9	14.4	29.8	1.5	3.1		
51.8	108	53.4	111	59.9	125	...	...	8.1	16.8	1.6	3.3	6.5	13.5		
54.5	120	72.2	159	129.6	285	2.5	5.5	75.1	165	17.7	39	57.3	126		
50.0	100	60.5	121	64.3	129	1.8	3.6	14.3	28.7	10.5	21.0	3.8	7.7		
42.4	73.6	73.2	127	75.4	131	...	...	33.0	57.3	30.8	53.4	2.2	3.9		
55.9	127	66.5	151	68.5	155.5	...	...	12.6	28.5	10.6	24.0	2.0	4.5		
46.6	87	75.2	140.5	80.2	149.7	...	...	33.6	62.7	28.6	53.5	5.0	9.2		
56.5	130	63.2	145.5	63.6	146.3	...	...	7.1	16.3	6.7	15.5	0.4	0.8		
50.7	103	53.9	109.5	57.0	115.7	...	...	6.3	12.7	3.2	6.5	3.1	6.2		
53.7	116	54.8	118.4	55.5	119.8	...	...	1.8	3.8	1.1	2.4	0.7	1.4		
63.8	176	65.1	180	67.5	186	1.5	4.2	3.7	10.2	1.3	3.6	2.4	6.6		
63.1	171	65.1	176	66.1	179	2.9	7.8	3.0	8.1	2.0	5.4	1.0	2.7		
58	138	58.9	140	59.1	141	1.3	3	1.1	2.7	0.9	2.2	0.2	0.5		
60.4	153	61.8	156	61.9	157	1.2	3	1.5	3.9	1.4	3.5	0.1	0.4		
65.5	190	66.5	193	66.9	194	1.4	4	1.4	4.1	1.0	2.9	0.4	1.2		
61.8	162	62.5	164	...	...	0.8	2	...	...	0.7	2.0	...	...
64.2	179	66.0	184	66.8	186	3.6	10.2	2.6	7.4	1.8	4.9	0.9	2.5		
57.5	136	59.0	138	...	...	1.3	3	...	...	1.5	3.6	...	...
59.3	146	60.4	149	...	...	...	...	...	...	1.1	2.8	...	...
60.6	154	62.7	159	63.2	160	1.8	4.5	2.6	6.5	2.1	5.3	0.5	1.2		
59.0	144	61.6	150	61.8	151	2.2	5.4	2.8	6.8	2.6	6.4	0.2	0.4		
65.3	189	68.0	197	68.4	198	...	...	3.1	8.9	2.8	7.9	0.3	1.0		
57.9	138	60.8	145	60.9	145	...	...	3.0	7.1	2.9	6.9	0.1	0.2		
52.8	112	56.9	121	56.8	120	...	...	4.0	8.4	4.1	8.7	-0.1	-0.3		
44.9	81.4	67.4	122	438	885	...	...	443	804	22.5	40.9	420	763		

† On the basis of Fe₂O₃ = 0 and Fe = 100% deoxidized.

In Fig. 2 it will be noted that although the curves refer to voids, porosities can be visualized in terms of their distance apart, *i.e.*, the separation of one curve from another indicates the pores entered by the fluid f_1 corresponding with the upper curve, but not by the fluid f_2 which corresponds with the lower; this difference equals $\Delta V_{f_1/f_2}$ (see equation (2)).

The smaller separation in the case of sinters indicates their lower general porosity. With regard to pressure porosity, the measurements available are of the same order for ores and commercial sinters; this shows that the pressure porosity is relatively more predominant with sinters. In fact, commercial sinters are generally singularly deficient in fineness of texture, approaching impervious material where $V_{Hg} = V_{H_2O} = V_{air}$.

There is no need, when dealing with mixtures, to carry out a separate experiment, provided that the constants relating to the individual components are known as well as the ratio in which they are blended. A

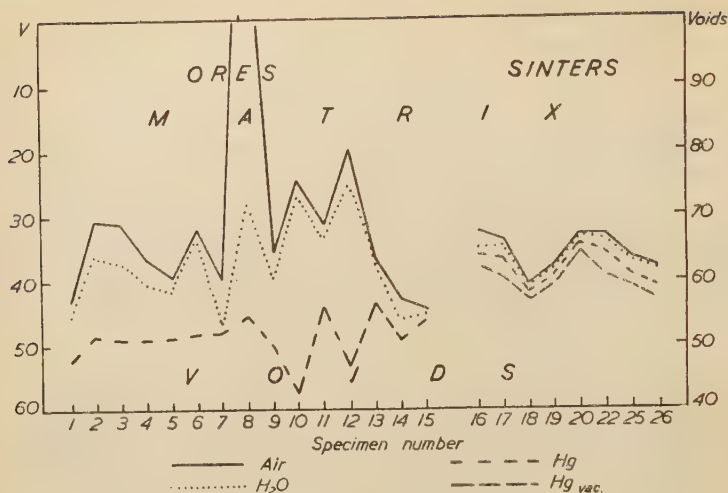


FIG. 2.—Porosity Determinations by S.K. Method.
($V + \text{voids} = 100$). For key to specimens see Table I.

comparison of the calculated and observed results for ρ_{Hg} and Voids_{Hg} for two mixtures of ore and sinter are as follows :

Mixture of ore and sinter (2 : 1 by bulk volume).

$V_{\text{Hg}} = 100$.

	Voids_{Hg}	$\rho_{\text{Hg}}(\text{g./ml.})$		Voids_{Hg}	$\rho_{\text{Hg}}(\text{g./ml.})$
Ore No. 9	100	3.00	Ore No. 2	106	2.24
Sinter No. 20	190	3.41	Sinter No. 19	153	3.51
Mixture found	122	3.09	Mixture found	123	2.61
Mixture calculated	123	3.11	Mixture calculated	119	2.61

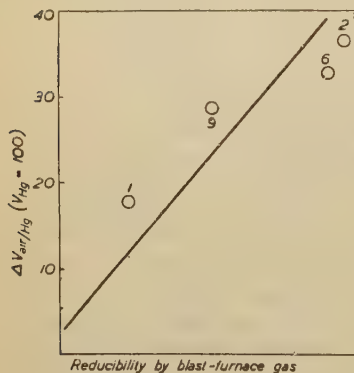


FIG. 3.—Relation of Reducibility by Blast-Furnace Gas to Porosity.

Tests on Ores.

(a) *Reduction*.—Porosity as determined by the difference between the bulk and powder densities of ores has been used as an index of reducibility by previous workers and for a long time the low reactivity of dense magnetites has been ascribed in part to their low porosity. However, the powder method is indirect and lengthy and suffers a further disadvantage in that completely sealed pores are necessarily included. This may introduce a considerable error when assessing a sinter, for it follows that such inaccessible surfaces would not be open to attack in a gas stream and consequently do not belong to the reacting interface. The substitution of

greatly minimizes this factor. Fig. 3 shows the relationship between $\Delta V_{\text{air/Hg}}$ and reducibility as determined by the method fully described in

"An Experimental Enquiry into the Interaction of Gases and Ores in the Blast Furnace," Part III.*

Although these ores, Nos. 1, 2, 6, and 9 (Table I.), vary considerably in origin and iron content (which latter is allowed for in the reducibility test), nevertheless the correlation points lie near a straight line and the order of merit remains identical. The test is equally applicable in differentiating between materials taken from the same mine. In the case of a Lincolnshire ore, for example, the porosity was found to diminish from the top to the bottom of the bed and the reducibility varied in a like manner (Nos. 3, 4, and 5). With a group of Mesabi ores from different mines (Nos. 11-15) the reducibility was once again found to follow the air/mercury porosity. Shenango yellow (No. 12) is worthy of special mention, as its porosity is the highest yet encountered with a matrix volume (V_{air}) of only 20%; a very high reduction rate might be therefore expected and this was fully borne out by the chemical test. Raimund ore (No. 15), which was the lowest in reducibility, shows almost the same values for mercury and air voids; thus the air/mercury porosity is practically nil.

Since crushing to a smaller size exposes an increased surface to the action of the furnace gases, it might at first sight be thought that therein lies a possible remedy for difficultly reducible ores; but it must always be remembered that increased fines may make a burden unworkable and these two factors therefore oppose one another. Thus in all cases there must be some optimum ore size to give the most economical working, quite apart from any problems relating to segregation which, however, would also be at a minimum when working with closely graded materials.

(b) *Carbon Deposition.*—In a number of cases definite correlation has been established between the values of $\Delta V_{\text{air/water}}$, i.e., the smaller pores measured by this test, and carbon deposition. The reaction $2\text{CO} = \text{C} + \text{CO}_2$ is essentially catalytic in character and therefore depends on the available surface of the gas-solid interface. As the reaction proceeds, the internal pressure occasioned by the accumulation of carbon constantly disrupts the material, exposing fresh surfaces to the action of gas, until finally the whole of the impregnated material is reduced to dust. This exposes an ever-increasing number of the finest capillaries.

Fig. 4 gives values of $\Delta V_{\text{air/water}}$ plotted against the carbon deposition index * (corrected for iron) for ores 1, 2, 6, 9, and 10. Ores 3, 4, and 5, from different depths in the same bed, likewise fell into line on the same basis.

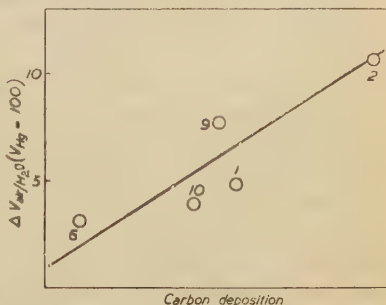


FIG. 4.—Relation of Carbon Deposition to Porosity.

Tests on Sinters.

Commercial sinters fall into a class by themselves. Almost the whole of their porosity is confined to the large cavities into which mercury can freely enter and they are in fact rather similar to agglomerates of glass beads. One of the main physical functions of sinter is to confer mechanical strength on the descending burden, so as to keep it open at a time when the ore matrix has been seriously weakened by the disruptive action of carbon deposition and increased pressure due to the superincumbent materials.

* *Loc. cit.*

Carbon is deposited only superficially on sinter and therefore little disintegration occurs.*

Conclusion.

Tests have now been made covering a fairly extensive range of materials and sufficient experimental evidence has been accumulated for it to be asserted that porosity measurements afford a rapid method for the comparative study of reducibility and should prove especially useful in deciding between the respective merits of differently blended mixtures of materials having approximately the same iron content, as well as in individual ore and sinter assessment.

Acknowledgments.

It should be stated that the experimental work embodied in this paper was carried out at the Imperial College of Science and Technology, South Kensington, for the Blast-Furnace Committee of the British Iron and Steel Industrial Research Council, by whom it was also financed.

CORRESPONDENCE.

Dr. T. P. HOAR (University Chemical Laboratory, Cambridge) wrote: In Fig. 3 of this interesting paper, the authors show the relationship between ore porosity and reducibility in the case of four ores, and draw a straight line—not the statistically best straight line—through the four points; this line cuts the $\Delta V_{\text{air/Hg}}$ axis at a positive value. This suggests that ores become irreducible while still showing porosity; one would have rather thought that even an ore with $\Delta V_{\text{air/Hg}} = 0$ should show some reducibility, and that any line relating the two properties must in fact cut the reducibility axis at a positive value. It happens that for the four points shown such a line would have to be a curve concave towards the reproducibility axis. I should like to ask the authors whether they have by now any more results that support or rule out such a $\Delta V_{\text{air/Hg}}$ relationship, and whether they have any further theoretical ideas that might lead to this or any other relationship?

Dr. H. A. DICKIE (Messrs. Stewarts and Lloyds, Ltd., Corby) wrote: The authors' ingenious method reveals interesting differences in the type of porosity existing in various ores, and shows clearly the differences between ores and sinters in this respect. It is, however, more than doubtful whether one could exclude from consideration pores which might become exposed during heating in the blast-furnace. It might also be expected that the rate of reduction would be conditioned by other variable factors, such as cracking and disintegration, which influence the access of the reducing gases.

The authors' method, as described some years ago, was tried out at Corby on Northamptonshire ores of ferric, ferrous-ferric, and ferrous types, and on a few widely different types of hematite and a magnetite. Porosity was also determined by the powder method. The results were compared against the time required for reduction of standard-sized cubes of the pre-ignited ores in both hydrogen and carbon-monoxide atmospheres at standard temperatures, and with a constant rate of gas flow. Very little connection could be seen in these tests between the porosity, as determined by either method, and the reducibility. A certain range of samples could be picked out which showed a connection, but there were too many exceptions, sometimes wide exceptions, to allow the porosity, either in the initial condition or in the ignited condition, to be accepted as an index of the reducibility.

* See "Sinters and Sintering" by Saunders and Tress, *Journal of The Iron and Steel Institute*, 1945, II., pp. 303 P-315 P (this volume).

TABLE A.—*Coke Porosity Data.*

No. N.O.R.O.	Material.	C.A.B.* Ou. ft./ min.	ρ_{Hg} g./ml.	γ_{Hg}	Voids.				ΔV .			
					Hg (vac.).	Hg.	H ₂ O.	Air.	p.	Air/Hg.	H ₂ O/Hg.	Air/H ₂ O.
662	1 $\frac{1}{2}$ -2 in. anthracite.	0.01	1.38	53.6 100	41.5 78	46.4 87	47.6 89	64.3 120	4.9 9.1	17.9 33.4	1.2 2.3	16.7 31.1
723A	1 $\frac{1}{2}$ -2 in. coke.	0.039	1.46	35.6 100	...	64.4 181	66.7 187	73.6 206	...	9.1 25.6	2.2 6.3	6.9 19.3
712		0.056	1.59	32.2 100	...	67.8 211	69.6 217	76.4 238	...	8.6 26.6	1.8 5.7	6.7 20.9
723S		0.060	1.57	39.4 100	...	60.5 154	62.9 159	65.4 166	...	4.9 12.3	2.3 5.9	2.5 6.4
710		0.067	1.76	37.3 100	...	62.7 168	65.2 175	67.0 180	...	4.3 11.5	2.5 6.6	1.8 4.9
722A		0.069	1.73	36.9 100	...	63.1 171	65.1 176	66.6 181	...	3.6 9.7	2.0 5.4	1.6 4.3
722S		0.071	1.74	36.2 100	...	63.8 176	66.0 182	68.3 188	...	4.5 12.4	2.2 6.0	2.3 6.4
	1 $\frac{1}{2}$ -2 in. blast-furnace coke . . . . .	...	1.48	31.7 100	59.7 188	68.3 215	69.9 220	71.9 226	8.6 27.1	3.6 11.2	1.6 5.0	2.0 6.2

* Critical air blast.

When, however, the times for 90% reduction were plotted against the weight of iron in the standard-sized cubes it was found that the reduction time was directly proportional to the weight of iron present. This was the case in both atmospheres, and both curves passed through the origin, *i.e.*, when no iron is present the reduction time will be zero. The three widely different hematites fell on or near the linear curve, as also did the average values of Northamptonshire ores of limonite, siderite or chamosite-siderite types. At the same time there was a considerable scatter in the values of individual constituents of Northamptonshire ores, but since a normal ore face contains a number of constituents, these would usually be expected to average out to a value not far from the curve. The magnetite was the only ore tested which failed to conform to the rule. Its porosity differed only slightly from the densest hematite tested, so that the magnetite was out of step on the basis either of porosity or of weight of iron in unit volume.

Naturally, the porosity enters as a factor into the above method of expression, since, in ores which are otherwise similarly constituted, the amount of iron in unit volume will vary inversely as the porosity. It seems necessary, however, to conclude that the reduction time varies inversely as the volume occupied by the pores plus gangue, since this volume will be the true complement of the weight of iron in unit volume, or, perhaps more accurately, of the volume of the iron compounds present. It seems, therefore, that in an average case the gangue acts virtually as pore space, but in certain cases it may, of course, affect the result if it forms an envelope or shield round the iron-bearing particles.

If it is true as an approximation that the reduction time varies directly with the weight of iron in unit volume, then a rapid index of the reducibility can be obtained from the percentage of iron in the ore and the bulk density. It is not suggested that this will necessarily give more than an approximate assessment, since other factors, such as the structure of the ore and the behaviour during heating, may require consideration.

One apparent objection to the authors' method in use is that when using friable ores it is necessary to clean out the apparatus after each determination. The principles of their method might, however, be adapted to a ready and quick determination of the bulk density on samples representative, for example, of an ore face.

AUTHORS' REPLY.

The AUTHORS wrote in reply: Owing to the absence of sufficient data relating to ores of very low porosity it is not possible to determine any curvature of the line relating porosity and reducibility. Presumably an impervious ore will still possess a certain reducibility by virtue of its external surface (though the case is rather hypothetical); therefore the line was drawn as in Fig. 3 to allow for this as the best compromise. The rate of reduction will certainly be influenced by such factors as disintegration, which may or may not affect porosity. Measured porosity would necessarily include fissure cracks which would ultimately produce a greater tendency to cleavage. No method can be absolute which does not reproduce blast-furnace conditions; for the same reason it is most difficult to make comparisons between results obtained under widely different experimental conditions; attention is, however, drawn to the improved technique over the method as originally reported (privately). In the case of the ores mentioned reducibility follows the amount of iron in unit volume; this is a factor which merits further study, especially in the case of magnetites. In response to requests for porosity data relating to coke, those given in Table A may be of interest.

For further Correspondence on this Paper see the *Journal*, 1946, No. I.

SINTERS AND SINTERING.—PART I.*

By H. L. SAUNDERS, PH.D., F.R.I.C., AND H. J. TRESS, PH.D. (IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, SOUTH KENSINGTON).

(Figs. 1 to 10 = Plates XXX. to XXXIII.)

SYNOPSIS.

Sinter in the blast-furnace burden is beneficial in spite of its lower reducibility as compared with ore; hence any improvement in quality of the sinter would be reflected in fuel economy, provided it behaved similarly in preserving an open burden. In this connection differences in the behaviour of ore and sinter towards furnace gas are considered. Some of the changes occurring during the various stages of sintering are outlined, with special reference to the effect of temperature on porosity and strength. From a study of laboratory sinters prepared under controlled conditions, changes in texture have been followed, and it is shown that in usual commercial practice the bonding temperature is far too high, with the result that unnecessary slagging and loss of porosity result. The need for closer control is stressed, and various suggestions for modifications to existing plant are made.

I.—INTRODUCTION.

THE blast furnace is a long-suffering machine that year in and year out is expected to achieve a reasonable output of iron on the crudest of diets; the marvel is that any survive a lifetime of a million tons output. The use of sinter in the burden is a development of comparatively recent date and has been acclaimed with varying degrees of enthusiasm as an antidote to many ills. Yet, beyond the fact that sintering affords a valuable means for the utilization of fines, opinions regarding both the essential qualities of a good sinter and the chemical changes involved during its manufacture are as diverse as the constituents from which the sinter is made. So often is this state of affairs the consequence of an inadequate scientific background. We first encountered sintering when studying high-temperature equilibria, and had to take special precautions to eliminate it. More recently the subject has re-appeared in connection with reducibility tests; we have since examined the problem from many other angles and it is now possible to make a general survey of the physical and chemical changes involved, together with a more detailed study of special aspects of the process which seem to have an important bearing on the future development of blast-furnace technique. Large numbers of laboratory-made sinters, in addition to a dozen or more commercial samples, have been examined. By preparing the laboratory specimens under carefully controlled conditions, it has been possible to correlate various factors which will be described. Although the data may still be incomplete, it is felt that a critical survey in the light of present knowledge may help to clear the way for a better understanding of, and possible improvements in, sinter production.

The reducibility of an ore is closely related to its porosity and the same has been shown to be true of sinter. The majority of the commercial products examined show a value of only a few per cent. on the S.K. porosity test † ($\Delta V_{\text{air/Hg}}$ about 5), even though made from widely differing types of

* Received March 2, 1945.

† All porosities in this paper are on the basis of $V_{\text{Hg}} = 100$.

S.K. = South Kensington. For a description of the test see Saunders and Tress, *Journal of The Iron and Steel Institute*, 1945, No. II., pp. 291 p-300 p (this volume).

material; this suggested that some inherent limiting factor is operative. Although they are generally much less easily reduced than ores, it is a well-established fact that sinters in the blast-furnace burden are advantageous, and some explanation of this seeming contradiction is therefore necessary.

Physically, there is a fundamental difference between the structure of sinters and that of the ores from which they are made, which is immediately apparent upon inspection. The predominant pores in an ore are not obvious to the naked eye, whereas, in the case of a sinter, the cavities range in size from something just perceptible up to those which can be ranked as "approaching voids." The S.K. porosity test has proved of considerable value in classifying sinters according to their textures and in determining the distribution of pore size in relation to heat-treatment; generally speaking, the pressure porosity is the best criterion for assessment. If, therefore, porosity could, by any means, be increased, greater advantage might result, as not only would the sinter still confer its beneficial influence upon the working of the furnace burden, but it would itself be more easily reduced to metal and thus lead to an economy in fuel.

Chemically, one advantage arising from the use of sinter in the blast-furnace burden is bound up with carbon deposition. This reaction, occurring in the upper region of the stack, is catalysed by a variety of materials, including deposited carbon itself. Its disintegrating influence on all classes of ores has often been pointed out (*see* Fig. 1). Sinters behave differently. Whereas in the case of ores impregnation precedes deposition, in the case of sinters there is very little impregnation, and because of the high strength of the matrix, disintegration is virtually absent (*see* Fig. 2). The deposited carbon shows very little tendency to key and is easily detached by the movement of the burden and by blast, thus preserving a high percentage of voids in a region where the fines may otherwise predominate and so assisting a freer distribution of blast.

There is also a substantial volume decrease during sintering, so that again, given a good-quality sinter, what really amounts to an enrichment of the burden takes place.

II.—OUTLINE OF COMMERCIAL SINTERING PROCESS.

Fundamentally, sintering may be regarded as a means for utilizing fines. There are three main stages in sinter production: (1) Preparation of the raw materials; these usually consist of ore, flue dust, mill scale, &c., which are mixed with the requisite coke and water and spread on some form of grate; (2) ignition of the mass; and (3) combustion of the fuel, maintained under suction to completion, when bonding occurs. Immediately after ignition, when the hot gases commence to traverse the bed, the transition of some of the water to steam disrupts the larger material; most of the fines suffer balling during mixing and are therefore submitted to a relatively slower steaming so giving a measure of porosity to the bed without disintegration. Decomposing carbonates perform a somewhat similar function, though at a higher temperature. The net result is the production of a general fluffing throughout the mass. Whether ignition is initiated on a carbon-enriched surface or otherwise, the time required and the rate and uniformity of its progress will depend on the porosity of the bed, so that the distribution both of the voids and the carbon is of vital importance. Practice varies from plant to plant, the ignition time being usually left to the experience of the operator. Few reliable measurements are available of either the rate of heating or the maximum temperature attained in the commercial process; the temperature appears to vary between 1150° and 1700° C. and locally the higher

SURFACES EXPOSED BY NATURAL FRACTURE. SPECIMENS NOT PREPARED
IN ANY WAY.



FIG. 1.—Carbon Deposition on Ore. $\times 5$.

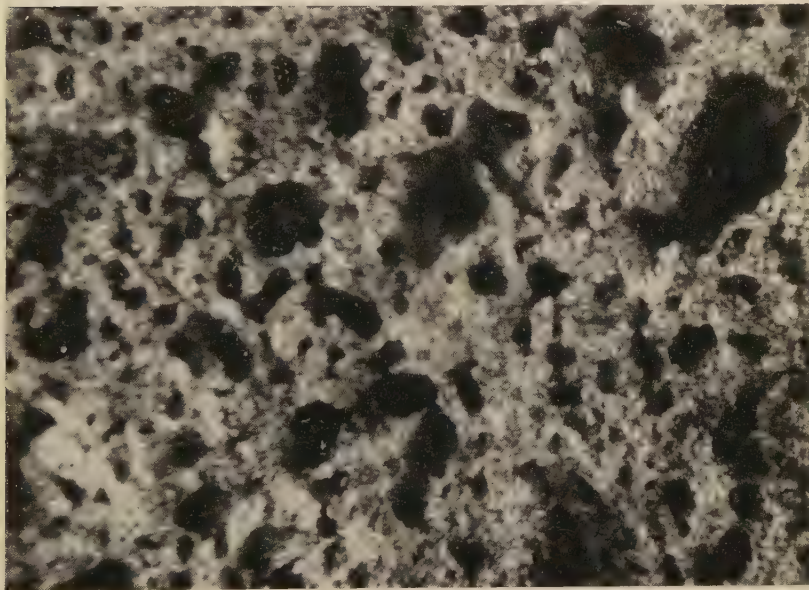


FIG. 2.—Carbon Deposition on Sinter. $\times 5$.

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SURFACES EXPOSED BY NATURAL FRACTURE. SPECIMENS NOT PREPARED
IN ANY WAY.



FIG. 3.—A Fine-Grain Laboratory Sinter. $\times 5$.

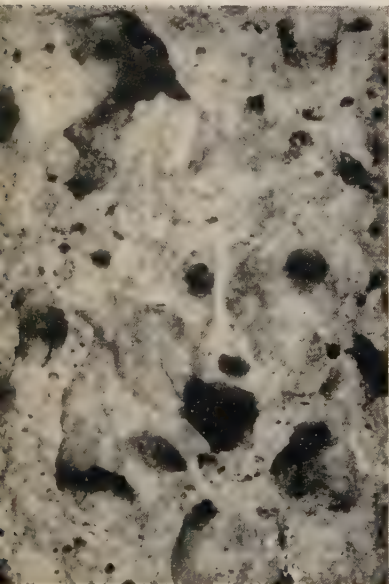


FIG. 4.—Commercial-Type Sinter Prepared in Laboratory. $\times 5$.



FIG. 5.—Sinter Made at 1140°C . $\times 5$.

SURFACES EXPOSED BY NATURAL FRACTURE. SPECIMENS NOT PREPARED
IN ANY WAY.

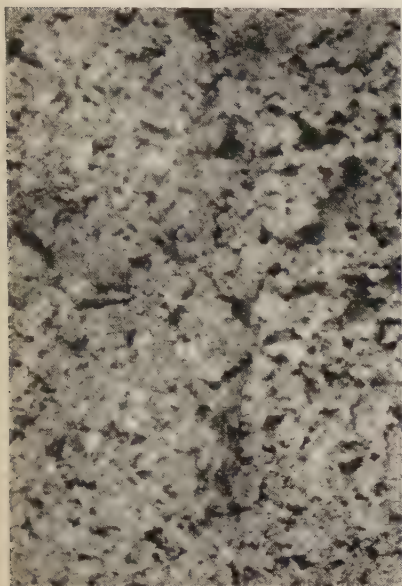


FIG. 6.—Sinter Made from Same Mixture as Fig. 5,
but at 1150° C. $\times 5$.

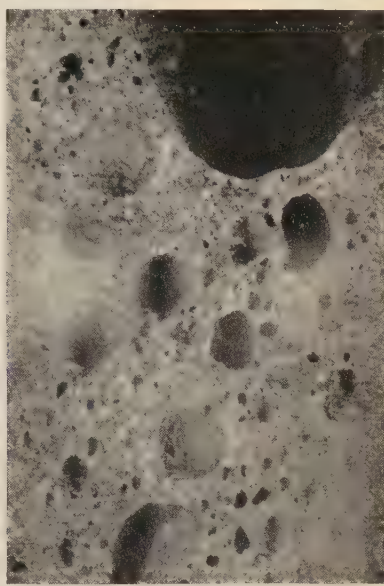


FIG. 7.—Sinter Made from Same Mixture as Figs. 5
and 6, but at 1160° C. $\times 5$.

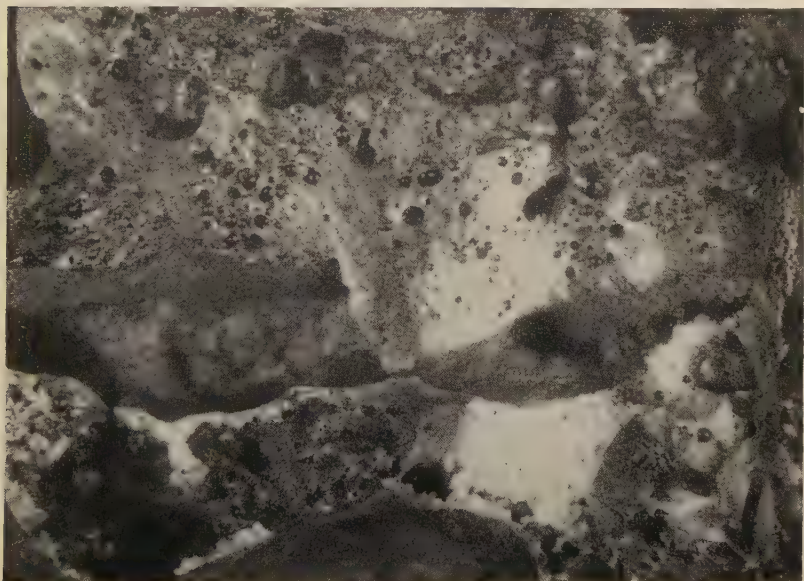


FIG. 8.—Commercial Sinter. $\times 5$.

SURFACES EXPOSED BY NATURAL FRACTURE. SPECIMENS NOT PREPARED
IN ANY WAY.

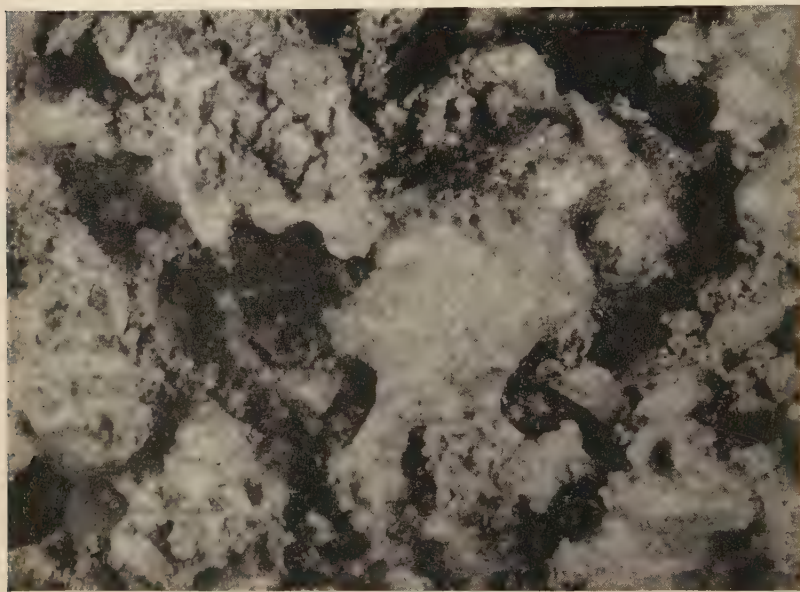


FIG. 9.—Example of Tree-Like Growths. $\times 5$.



FIG. 10.—Example of Binding at 120°C . $\times 5$.

value may even be exceeded. However that may be, conditions are such that partial fusion invariably results. Although control during stages 1 and 2 may be of considerable importance in determining the nature of the final product, it will be necessary in the first instance to deal more specifically with bonding, which occurs in the third stage.

Several reactions take place in bonding. Whilst some of the coke is necessary to maintain the temperature by combustion, a certain amount of it takes part directly or indirectly in the reduction of ferric oxide. In several samples analysed, the figures ranged between 8 and 15% deoxidation. In view of the proportion of coke present in the mix, this is somewhat surprising from the purely theoretical aspect. One is therefore forced to the conclusion either that too much coke is allowed to burn externally to the ore (*i.e.*, there is inadequate mixing or too high suction) or that the reduced material subsequently undergoes re-oxidation in the air stream whilst still at a high temperature. In addition, many sinters are characterized by a dark, semi-vitreous bond of iron slag. Here it should be remembered that iron and other silicates, however satisfactory they may appear as mere agglomerating agents, are nevertheless known from experiments to be reducible only with difficulty, and by reason of their easy fusibility and high solvent action, serve only to flow over and clog the pores of the very material that is added to maintain an open burden.

As the temperature of the sinter bed approaches 1000° C. much of the true Fe_2O_3 disappears. The first reduction stage ($\text{Fe}_2\text{O}_3 \rightarrow \text{Fe}_3\text{O}_4$) is irreversible, so that it will probably proceed to completion. In the second stage ($\text{Fe}_3\text{O}_4 \rightarrow \text{FeO}$) the CO/CO_2 equilibrium ratio falls with rising temperature and as the reaction velocity at 1000° C. is reasonably high, the reduction will be carried to some point between the Fe_3O_4 and FeO stage in the time available, provided the necessary carbon is available. Whether such a reduced condition still exists in the finished product depends naturally on the absence of subsequent oxidation. So far as the oxides of iron are concerned, the bonding agent is FeO in combination with either Fe_3O_4 or Fe . (These complexes have a considerable plastic range.) The characteristics of the bonding process change rapidly as the temperature is raised another 250° C. Complex silicates make their appearance as centres of fusion, together with a certain amount of fayalite. The whole of this later stage, which is nothing more than slag formation, should be relegated to its proper place, *i.e.*, to the furnace hearth, where most of the ore is reduced to metal; there is no point in introducing slag at the stockline, especially in the form of a coating over potentially good material.

Sometimes iron-carbon eutectic is found where the reduction has been very localized. This, however, gives quite a different type of bond, which is free melting and not detrimental to quality.

It is possible, therefore, to differentiate between three types of bond, which may occur either singly or in any combination: (a) iron oxide, (b) ceramic (of low iron content) and (c) iron silicate (essentially fayalite). The quality of the sinter depends to no small extent upon the time/temperature relationship throughout the whole process.

In the initial stage, if the rate of steaming is insufficiently rapid, the texture may be so close that combustion of the coke is far too slow to give a good product. A similar trouble occurs with excess fines and unbalanced moisture. An increase in volume without loss of cohesion is necessary at this stage for the production of a good sinter, and this can be controlled within limits by regulating the water content, the depth of material, and the suction of the fans. The size of the coke needs careful adjustment also, for it is evident that in the limited time available for the entire process a high surface/weight ratio is essential to secure the necessary heat output

with the minimum fuel. In view of the limited extent of the combustion zone at any instant and the large excess of air, most of the carbon may be burnt to CO_2 . This may lead to an unnecessarily high local temperature and constitute a waste of coke. It is difficult to say whether any CO generated in the second stage of reduction ultimately reacts with oxide of iron or air.

III.—SINTERS PREPARED IN THE LABORATORY.

All commercial sinters so far examined have had a relatively low porosity, typical values (S.K.) being as follows :

	ΔV_p .	$\Delta V_{\text{air/Hg.}}$	$\Delta V_{\text{H}_2\text{O/Hg.}}$
(i)	3	3	2
(ii)	4	4	3
(iii)	3	4	3

Laboratory sinters, however, prepared under rigid control from similar ores, can be produced at will with widely different textures, including those with the same characteristic appearance and porosity as the commercial types. The temperature variable is most important and will be considered first. The raw materials were not ignited in the usual way, but were placed, after the addition of water, in a refractory container and heated under carefully regulated conditions; the whole of the carbon content was then available for oxide reduction, the necessary thermal requirements being met externally in an electric furnace. By this means one of the two functions of the carbon can be isolated and studied separately. No attempt has yet been made to ascertain in what proportions the carbon divides itself between the two reactions. This will depend upon the intimacy of mixing and the size of the particles, and will vary with temperature and time of heating. At the moment we shall restrict ourselves to the reduction of the charge whereby the oxide bond is produced. For this, a minimum temperature of about 1150°C. is necessary and the temperature need not exceed 1350°C. except in unusual circumstances.

Porosity and Strength in Relation to Temperature.

The first thing to be noticed in the case of laboratory sinters is that unless the temperature is allowed to rise unduly high, the material produced is quite different from the commercial products and possesses a very much higher porosity (see Fig. 3). The best specimens approach in appearance compressed fine steel wool, but are granular rather than fibrous in structure and are very strong mechanically. A very wide variation in porosity and strength is obtainable by the control of temperature alone. At the bottom of the scale, where sintering just begins, the sinters are rather friable but exceedingly porous. As the temperature is raised the strength increases rapidly and the porosity falls until ultimately they become vitreous, the texture ceases to be granular and becomes vesicular, finally resembling volcanic rock (see Fig. 4). It often happens that the transitions are irregular, and a temperature increment of only 20°C. may make all the difference between the production of a good and a bad sinter (Figs. 5, 6 and 7); these were three sinters made from the same raw materials heated to 1140°C. (Fig. 5), 1150°C. (Fig. 6), and 1160°C. (Fig. 7). It will therefore be seen that for the production of high-grade sinters much more rigid temperature control is necessary than that commonly exercised, or, indeed, than that which it is possible to exercise on an open grate. If the material were made in some kind of kiln under thermostatic control, it is certain that a much more uniform and reactive product would result; moreover, oxidation could be eliminated and any carbon monoxide (generated from

the action of the carbon on oxides of iron) which was not utilized in gaseous reduction might be recovered (*e.g.*, reducing atmosphere) or burnt to useful purpose elsewhere.

With most commercial sinters, even when due care is taken to avoid a glassy product, much of the surface appears to have been heated considerably above its melting temperature, thereby eliminating porosity (*see* Fig. 8). In the prefusion stage masses of material often aggregate together giving tree-like growths (Fig. 9). No doubt these are advantageous to some degree, but the structure is one of high voids and not true porosity. These tree aggregates are ideal regions for the surface combustion of carbon monoxide, since they promote channelling of the gas stream. Not only is the potential reducing power of the gas (for bond formation) wasted, but they become centres of maximum shrinkage and therefore increased temperature—the process being self-aggravating—until they fuse completely to give an impenetrable clinker. Overheating also means higher oxidation losses during cooling.

It may well be argued, why go to the trouble of preparing a low-temperature high-porosity sinter when it will be subsequently heated to a much higher temperature in the furnace? The reply to this is that in the furnace the sinter will be subjected to the continuous action of the blast-furnace gas for a period of some hours, during which it will, if sufficiently permeable, undergo substantial reduction before fusion. Moreover, as its iron content increases, its new melting point continuously rises, while it retains that high permeability which is so desirable.

The time and degree of the heat-treatment of a sinter mixture afford the necessary scope for exercising control over the final product. It may not be generally realized that this control begins as low as 750° C., that is, well below the temperature under the ignition hood. Thus, when the surface of a sinter bed has been ignited and suction applied, heat exchange between exhaust gas and solids raises the temperature of the latter some distance in advance of the combustion front sufficiently to initiate deoxidation of the ore, even in the presence of much CO₂. It is true to say, however, that this is conditional upon good ore-carbon contact. It makes little difference whether all the heat is supplied internally (by combustion of fuel) or partly from external sources (as in laboratory experiments); some reduction immediately occurs before even the lowest bonding temperature has been reached. It is very easy to see, therefore, that the composition of the mixture (*i.e.*, the Fe/O ratio) may vary considerably according to the time taken in heating the material during this presintering stage. The rapid increase in reaction rates above 1000° C. (especially for low degrees of reduction) will tend to overshadow these early changes, so that a mixture slowly heated to, say, 1200° C. may give much the same oxygen loss as one more rapidly heated to 1250° C., and yet the textures in the two cases may be totally different. By control of the composition when the bonding temperature (which will vary according to the impurities in the ore) is *first* reached, the formation of some undesirable low-melting-point compounds may be avoided. It would, of course, be much easier to exercise such control by external heating.

In an air-draught process, sulphur can be burnt to provide some of the necessary heat and at the same time reduce the sulphur content of the ore. This, however, is a matter demanding critical control if satisfactory elimination is to be achieved. The melting point of iron sulphide is very low and this compound is produced all too readily, especially in a reducing atmosphere. Once formed, it will only add to the difficulties associated with low fusibility and subsequently lead to a low reactivity.

The Ore/Carbon Ratio.

Whilst it is true to say that almost any mixture of coke, ore, scale, and other scrap will produce some kind of agglomerate which could even be used in a blast furnace, a good-quality sinter needs considerable care in the selection and blending of its constituents. It is not essential that the whole of the oxide present shall be reduced to some theoretical composition, because, provided sufficient bond is available, and neither time nor temperature is unduly increased so that oxygen becomes uniformly distributed, the remaining oxide is held in suspension in the same way as the gangue of the ore. On the other hand, if the reduction is high, bonding still obtains and may indeed be less subject to vitreous inclusions when self-fluxing ores are employed. However, an excess of carbon above any theoretical optimum is necessary with present-day commercial sintering in order to raise the raw materials to the requisite temperature. It is quite impossible to generalize, for the relative appropriation of carbon for bonding and heating is certainly a very complicated function of rate of heating, suction, size grading, reactivity of ore and coke, intimacy of mixing, and distribution and porosity of the bed, quite apart from any special carbon requirements necessary to control the location of the oxide bond within certain reduction scale limits for counteracting specific tendencies in different mixtures. If the carbon is too low, a poor sinter results; if too high, a serious wastage of fuel. The ultimate choice must be based on experimental tests; quite small variation in the raw materials can produce serious consequences. At first sight it seems advantageous to combine heating and bonding in one operation, but the quality of the product is not always satisfactory and is of considerably lower reducibility than need be, so that fuel requirements in the furnace will be increased. The laboratory method opens up possibilities of improvement; the reactions are separated and the examination of temperature/porosity relationships for a given percentage of "bonding" carbon (now easily calculated) gives much useful information.

Generally speaking, when the carbon requirements are kept down to a minimum the optimum sintering temperature is critical, particularly with certain ores. It is best in all cases to make up trial mixtures and then compare porosities and strengths. This makes it easy to assess the full range of useful carbon content, and calculation on the basis of a mean value will give the maximum latitude without sacrifice of quality.

Extension of Sintering Range.

The sintering temperature range is raised and extended if the carbon content is increased; this is due to the fact that more reduction occurs below the temperature of incipient fusion, so that by the time the materials have been heated to the bonding temperature, *ca.* 1150–1200° C., the Fe/O ratio is no longer that demanded by theory, and the melting point is raised progressively as reduction proceeds. This knowledge can often be usefully employed to give a material of more open texture.

Flue dust contains both ferric oxide and carbon, but the proportions of the constituents are such that there is a large excess of carbon and it is difficult to make sinter from this material alone. If, however, it is mixed with even an equal weight of ferric oxide (or its equivalent as mill scale) sinters are then practicable in spite of a 2.5 times excess of carbon. This mixture makes a very instructive study, emphasizing a number of points that have been dealt with in the text. About fifteen mixtures were made up in the 1 : 1 ratio and each heated and held at a selected temperature for 10 min. (Table I.). The temperatures employed varied from a minimum of 1130° up to 1490° C. and nine of them gave a product classifiable as a sinter, that is to say, the material was coherent and needed a hammer blow to

cause fracture. For mixtures other than 1:1, a somewhat different temperature range was indicated. At 1130° C. the mass was coherent but could be broken by hand. Between 1140° and 1400° C. the product was hard and compact and the density curve showed a first maximum at 1160° C., decreasing thereafter to 1200° C. and then gradually rising to 1410° C. The porosity, ΔV_p , gradually fell with rising temperature and it is notable that the smaller pores, $\Delta V_{\text{air/Hg}}$ and $\Delta V_{\text{H}_2\text{O/Hg}}$, were very low. The sintering range was nearly 300° C., which is very considerable. At 1490° C. the mixture assumed a slag-like appearance.

TABLE I.—*Properties of Sinters Made from Ferric Oxide and Flue Dust (1:1) with Excess Carbon.*

Temp. °C.	ρ_{Hg}	$\Delta V[V_{\text{Hg}} = 100]$			Remarks.
		p .	Air/Hg.	H ₂ O/Hg.*	
1130	...	>75	Feebly fritted. Crumbly. Bonded.
1140	4.27	64	12	10	
1150	4.35	30	6	4	
1160	4.50	32	7	5	Strength gradually increasing with rising temperature.
1180	4.36	24	5	5.5	
1200	4.33	23	9	7	
1225	...	...	...	...
1290	4.49	32	4	5	
1300	Iron slag over surface. Much slagging. Separation of metal and slag.
1355	4.48	28	2	7	
1405	4.51	19	2	4.5	
1450	...	<10	...	...
1510	...	0	...	...

* Includes hydration.

Density Variations during Sintering.

From experimental data it may be said that during the early stages of sintering there is a general increase in density which is due to the combined loss of oxygen and carbon and the shrinkage in volume. The increase is not always regular and varies with the amount of carbon initially present and the nature of the ore. For any fixed iron/carbon ratio, where reduction is below about some 30%, the value increases to a maximum and then begins to fall as the sinter blisters. The maximum value generally corresponds to a good-quality sinter. With carbon present in excess of ordinary sintering requirements, the density may first reach a maximum and, after falling as before, show a second gradual rise until all the carbon is destroyed, the loss due to blistering being more than offset by the gain in metallic content.

Alternative Heat-Treatment.

Although it may be the usual practice to heat the sinter mixture as rapidly as possible to its final temperature, this may not always be advisable, especially in the case of self-fluxing or green-ore mixtures. In such cases it can be shown that by elimination of the higher oxide in a pre-sintering stage, many of the difficulties normally associated with a high ferrous content can be avoided, and the reactive oxide formed from the decomposition of green carbonate undergoes further reduction instead of combining with silica or silicate to give the "black melt" which penetrates everywhere to the general detriment of the sinter and everything in contact with it. An excess of carbon, with thorough mixing, seems

preferable, followed by a two-stage heat-treatment, the first at a temperature near, but below, 1000°C ., followed by a short period above 1200°C . Although this takes longer, it may still be economical, since the reduction of the Fe_2O_3 and Fe_3O_4 is carried out at a low CO/CO_2 ratio and under conditions of maximum porosity. Subsequent bonding then ensures a spongy but strong metallic matrix, which may, if the initial carbon content was sufficient, still hold within its interstices enough carbon to effect a substantial part of its ultimate reduction and present in the ideal state of intimate contact with the remaining oxide.

Nature of Added Carbon.

It is by no means essential that the carbon initially present in the sinter mixture should be in the form of coke, although this may be the more generally useful. Slack coal may be employed if the ash content is not too high. Coal will often give better ignition and with kiln sinter its swelling characteristics can be advantageously employed to adjust the texture of the final product, a point worthy of further study. Similar remarks apply to pitch, and some excellent laboratory products have been made with this material. The harder pitches are easier for mixing. Soft pitch might be incorporated in admixture with crude low-sulphur oils applied by spraying. Water and oil could be added together as an emulsion and a number of variations suggest themselves. No doubt other forms of industrial waste high in carbon might be usefully considered. Carboniferous ores make excellent raw material provided due account is taken of the associated iron oxide in computing the $\text{Fe}_x\text{O}_y/\text{C}$ ratio. In special circumstances the requisite reduction may be performed by waste reducing gas, although here certain modifications might be necessary to ensure adequate porosity.

IV.—PREPARATION OF RAW MATERIALS.

(a) *General.*

The most careful control of temperature and time of heating will be of small avail if sufficient care is not given to the adequate preparation of the raw materials, and here many difficulties arise. There is segregation at every stage owing to differences of both size and density and the tendency towards unequal distribution of moisture on particles of varying size, chemical composition, and texture. The appearance of the materials on the conveyor belts from the various storage hoppers is most deceptive; it is only when one inspects the grid at the mixer that one realizes the size and quantity of the lumps which are carried through unnoticed. Is the time allowed in the tumblers always adequate? The longer this time can be made the better, since any tendency toward further segregation (appearing for the last time at the grate-feed device) will be reduced, especially after wetting. Unfortunately the distribution at the feed may vary both laterally and vertically and this is doubly serious in a bed of such small depth.

Measurements show that in uniform beds the voids gradually increase as particle size decreases, yet the resistance to suction increases. Besides the normal effect due to subdivision of the voids, the air flow is being constantly forced to change its direction as it encounters each new obstacle. When the constituents are not uniform, but fall within definite size limits, voidage is determined by the relative proportions of the intermediates, and this determines the grading quality. In an extreme case the voids may be reduced to almost zero. Since it is current practice to use both ore and coke of some specified size "down to dust," it is fortunate that so simple a

remedy as the addition of water will eliminate this possibility of impenetrable beds.

(b) *The Optimum Moisture.*

What then is the optimum moisture content and how should it be made? The diversity of ores alone makes it obvious that no single figure will meet every requirement. Speaking generally, the addition of water (with, of course, proper mixing) first reduces and then increases the suction resistance, as illustrated in Fig. 11, which shows the variation of the resistance offered by a bed of material at constant air flow with progressive additions of water.

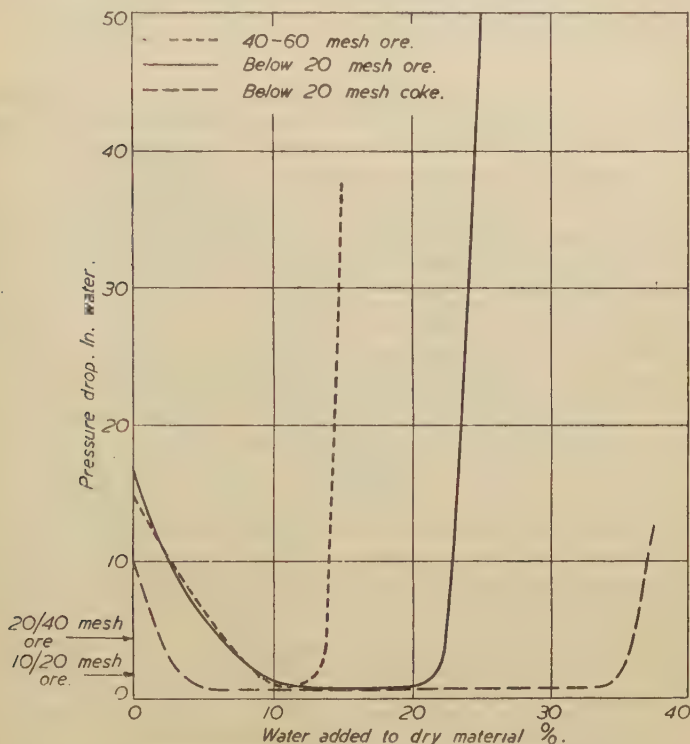


FIG. 11.—Variation of Air Resistance with Water Content.

On substituting a wide grading (20 mesh to dust), the low-resistance region becomes extended over a considerable range of water content. This ore had a useful water range of 8–21% and a similarly graded coke of 4–35%. These ranges will, of course, vary with the nature of the mixture employed and can be ascertained only by experimental tests, high coke usually conferring greater latitude. Near the mean value the materials have a characteristic appearance and are coherent under pressure, but assume their former friableness on remixing and give in the grate the essential openness of texture that is requisite for good ignition and indeed for the success of the whole process.

Water is best added in the form of a fairly fine spray, and there is also

something to be said in favour of steaming in the tumbling barrels (the difficulty here is accurate measurement and control). Occasionally the raw ore is already too wet, and dry material must be added.

It frequently happens that it is very difficult to incorporate water with certain substances in a fine state of subdivision, and in this connection some of the many wetting agents now on the market may be of considerable use. Several of the sulphonated oil, saponin, and soap types have been tried with considerable success. The main considerations would appear to be cost. (*See also under Flue Dust.*) During mixing, the water dissolves small amounts of soluble material and holds colloidal matter in suspension. This acts as a feeble plastic binder for the larger particles, securing a good quality for bedding, which is preserved through the steaming range. Fig. 10 shows this type of binding when a mix was heated to 120° C.

(c) *Size.*

Provided the materials can be handled, there is no theoretical lower size limit in grading. Indeed the finer the state of subdivision the greater is the closeness of contact, the more continuous is the combustion zone, while absence of excess carbon at any point keeps the ignition front moving and prevents local high temperature and ensures a more efficient low-temperature deoxidation. Nevertheless, such a mixture, even when balled to a suitable texture with addition of water, may possess disadvantages when used in the usual type of grate. Sufficient carbon must at all times be available for combustion to maintain the heat requirements of the process, *i.e.*, it must be located on the surface of the nodules. There is a great difference between a carbon granule surrounded by ore and an ore granule surrounded by carbon. The former is best suited to kiln sintering, the latter to normal practice. Bearing in mind the relative proportion of carbon to ore and assuming the particles of each to be of similar size, the continuity of carbon throughout the bed cannot be preserved. It can be made so only by increasing the surface, *i.e.*, using smaller coke than ore; also, as seen above, it must be so placed that a requisite proportion is in direct contact with the suction air. There is much to be said in favour of balling the ore with a small proportion of the total coke first of all and then adding the remaining coke as dust to the mixers and so producing carbon-coated nodules. It may be that the optimum heating time is directly related to the relative sizes of ore and coke used and any factor tending to extend this time, *e.g.*, high carbon (*vide* extension of sintering range), would increase the latitude in sizing.

Little is known about the selective coating in relation to size variation in the coating and coated material; if the interspaces between the coated ore granules could be filled with suitably sized ore which, heated by conduction in the presence of reducing gas, also underwent sintering, each variety would contribute its own specific characteristics to the composite properties of the double matrix. Much further experiment is needed on this matter before the best compromise can be stated with certainty. These arguments apply to laboratory and kiln sinters only in so far as the final texture of the material is governed by the equivalent mesh of its components, wetted or otherwise. In the externally heated sinter *all* the carbon can with advantage be much finer than the ore, even to the extent of being in colloidal admixture with the added water. This, however, would be of small value on the average grate.

(d) *Distribution.*

The use of materials up to $\frac{1}{2}$ in. on the grate introduces further complications due to maldistribution. Segregation occurs both in the feeders and chutes and again in the traverse of the bed. No experiments on small-

scale models have yet been made, but from observations of plants in operation it is evident that in some cases there is room for improvements. The exact manner in which this may be carried out will need special study. The depth of material fed per unit area may need alteration to reduce the danger of repetition patterns appearing at the centre and limits of swing.

The suction distribution at the bars also needs consideration. One has only to see the effect produced by a missing firebar to appreciate this point. Similar conditions apply to the bed whether this be composed of return fines or unsintered material, especially when the voidage approximates to the effective grate area. Another point also arises if return fines are used. This material may or may not be suitable according to the manner in which it behaves in the presence of hot reducing gases. If it is of such low permeability that there is danger of its melting instead of undergoing further deoxidation without loss of porosity, there may be danger of so changing the suction characteristics towards the end of the period as to cause a delay before the fans run light, and during this interval a large volume of air is drawn through the hot material with consequent unnecessary oxidation.

Suction Control.

The Greenawalt process will be considered first. When the suction of the whole grate is operated on one group of fans, some type of regulation appears very necessary. It is unreasonable to suppose that a suction governed entirely by the load characteristics will be the ideal. There should be an optimum air flow for ignition and adjustments for the top, middle, and bottom of the bed as the ignition front advances. Lack of such control is probably one cause of much overburnt material. From laboratory experiments there seems to be a good case in favour of the use of intermittent suction, the wind being eased at frequent intervals. During the rest period the hot spots will cool to a greater extent than the remainder of the bed, so that on starting up again the localized blow-pipe effect will cease to be progressive, and the combustion will proceed with greater regularity. It might also be possible to introduce steam or waste gas (high CO_2) from a hooded air intake.

In the Dwight-Lloyd process, even though there may be separate wind boxes for different sections of the run, these are usually operated on a single fan group, so that any alteration to the duct valves on one section will change the draught elsewhere. Each section should have its own fan and separate regulator which might be automatically controlled on the basis of the CO_2 or exit gas temperature.

The alternative to controlled suction is controlled carbon content over the depth of the bed, but this would complicate the feeding mechanism.

V.—RAW MATERIALS.

It now remains to consider special features associated with certain classes of raw materials.

Hematite Ores.

Although these are ideal materials in many respects, the moisture tolerance of the West Coast ores is decidedly lower than that of Rubies from Spain and Africa, and in some laboratory experiments difficulties have been experienced from the particularly gritty nature of the fines and the rather high silica when working on a low carbon content. Sierra ore sintered well with the normal quantity of carbon. With increased coke the optimum temperature could be increased to 1460°C. , porosity reaching a value between 50 and 60 for ΔV_p , accompanied by a

substantial increase in density and strength. Sierra/pitch mixtures (low carbon) gave a good porosity at 1200°C . ($\Delta V_p = 36$) without appreciable alteration on raising the carbon to normal. There was a decided increase in strength between 1150° and 1270°C ., accompanied by a fall in porosity. The micaceous Brazilian ores seem to be particularly good for sinter production, and it is hoped to examine these in greater detail in the near future.

Self-Fluxing Ores.

These form an interesting class inasmuch as bonding is possible even in the absence of carbon. Carbon will, however, usually be present and the exact nature of the complex bond will depend on its quantity and especially the heating time. The agglomeration due to the self-fluxing properties may prove detrimental to the production of a good sinter. It should be remembered that whereas a true sinter should be reducible by blast-furnace gas whilst still solid, a vitreous material behaves quite differently and unless it contains carbon in suspension within the bond, to be available in the hearth, gaseous reduction is impeded by the necessity for the gas to penetrate the slag coating.

These ores also possess an apparent long carbon range, and very careful adjustment of all conditions is necessary to secure correct texture as well as degree of reduction (*i.e.*, iron bonding). Appearance may be deceptive. Porosity tests in relation to oxygen content are very necessary for correct control. Addition of mill scale or even Al_2O_3 can be advantageously employed to counteract ceramic bonding.

Green Ores.

These may be blended with ferric ores. This may be preferable to conditioning by calcination, as the double loss of fuel (*i.e.*, in calcination and subsequent reduction) is avoided. The oxygen exchange takes place fairly easily, but such a process is better suited to a kiln-produced sinter. If sintering is carried out in the ordinary grate, much trouble may be experienced from excessive formation of "black melt."

Tests have also been made on the heat-treatment of turnings packed in green-ore fines. The mass breaks up well after sintering, the metal now being completely short as a result of oxidation.

Flue Dust.

Some samples carry enough carbon for the complete reduction of the iron oxide to metal, so that normally it is only employed in admixture with other ores. Moreover, it strongly resists water unless previously weathered, so that the use of a wetting agent is indicated. It can, however, be briquetted in a weak clay slurry (3-4%) and on heat-treatment at 1200 – 1400°C . it is readily reduced to iron; but this is a rather special problem outside the scope of the present paper.

VI.—CONCLUSIONS.

It is hoped that this general survey will give some indication of the many problems associated with sintering. There is no doubt that the commercial product can be improved if some form of temperature control is introduced. Various suggestions have been put forward and there may be others. Whilst the kiln method may prove to be the ideal, there is considerable scope for modification along the lines indicated and some combination of these may afford a useful compromise, especially when war-time controls are relaxed sufficiently to permit individual blending tastes to be satisfied. Meanwhile it will be well to remember that it is a mistake to use

any and every kind of iron-bearing material that happens to be at hand for the making of sinter, in the hope of securing its ultimate reappearance as metal, without due consideration of all the factors involved. Closer scientific co-ordination is imperative between the selection of the raw materials, the computation of the mixture, the grading of all constituents, the assessment of moisture, the control of segregation, and finally time/temperature regulation to secure a sinter suitably balanced as regards mechanical strength and high reactivity, best suited to the particular requirements of the furnace in which it is being employed.

VII.—ACKNOWLEDGMENTS.

The experimental work embodied in this paper was carried out at the Imperial College of Science and Technology, South Kensington, for the Blast-Furnace Committee of the British Iron and Steel Industrial Research Council, by whom it was also financed.

DISCUSSION.

Dr. L. REEVE (Appleby-Frodingham Steel Co., Ltd., Scunthorpe): Before coming to points of detail, I should like to say that it is very pleasant to see a paper on a subject such as sintering in the Institute proceedings. This is one of the very few papers we have had on this subject. Sinter plant has normally been regarded as a sort of dustbin into which anything can be put, and it is not surprising that the variability in the sinter plant is probably higher than in any other section of a joint iron and steel works.

This paper is really a combination of two papers; one deals with certain laboratory experiments on sinter, and the other, which is more or less intermingled with it, is an attempt to apply some of the results and to make practical suggestions to the sinter-plant operator. Taking the laboratory side first, I think that the method of working by heating ores at controlled temperatures is rather interesting. It ties up with some work which we ourselves have been doing. There are, however, one or two points of comment that I should like to make, which the authors may be able to clarify. I refer particularly to the set of photographs reproduced in Figs. 5, 6, and 7. With a particular mixture—I gather a self-fluxing mixture—a difference of temperature of $\pm 10^{\circ}\text{C.}$ is shown to produce remarkable differences in the structure of the sinter. If that is true—and I have no doubt that for these conditions it must be true—I should like to ask the authors whether these conditions must be regarded as artificial or whether they regard them as likely to occur in practice. I gather that the latter is the case; indeed, that may be the explanation of some of our troubles. If the sensitivity of the sinter mixture to temperature is as high as that, we are in for a difficult time. I think that the conditions must be slightly artificial, because later on, in their Table I., the authors show that over a fairly wide range of temperature—well over 100°C. —fairly good sinters are being made. More details of the constituents and sizing of the mixtures used would be of assistance. So much for the purely laboratory work. Criticism can obviously be made of the technique, but I think it must give very useful results if it is carefully and sensibly applied to practical conditions.

On the more practical side—it might be better to call it the control side—I am glad that Dr. Saunders, in introducing the paper, has emphasized the need for strong sinter. In my own view, too much has been said about the reducibility of sinter and not enough about its strength.

From the point of view of the practical man, strength is the variable which is far more important than reducibility. The blast-furnaceman's complaint is not that his sinter is, or is not, reducible, but that its strength is variable, *i.e.*, friable one day and strong the next.

I should like to make an appeal here for more systematic recording of the strength of sinter and to suggest that daily tests should be carried out by all sinter-plant operators. It may be recalled that in a Special Report * published last year, there is a description of a sinter shatter test devised by our Central Research Department; this is a small-scale test on a mere 300 g. of material which is very quickly done. We have adopted this test as a daily routine at the sinter plant at Appleby-Frodingham; eight tests are done daily and the average results are plotted on a quality-control chart which is in front of the sinter operator. We feel that more quantitative figures on the strength of sinter and its change from day to day should be made available so that we really know what a friable sinter is in terms of this test.

May I conclude by thanking Dr. Saunders and Dr. Tress for their very useful work and express the hope that Part II. of the paper will soon be available.

Mr. K. HEADLAM-MORLEY (Secretary, The Iron and Steel Institute): You may be interested in the practice which I saw recently at Domnarfvet, Sweden. The whole burden is sintered—the furnace is charged with sinter and coke only. Admittedly the conditions are exceptional and fuel economy is the primary consideration, owing to the present severe shortage of coal in Sweden. The ore used is a crushed concentrate from Grängesberg containing 64% of iron and 0.08% of phosphorus.

This is mixed with limestone, manganese ore and a certain amount of basic Bessemer slag (to raise the phosphorus content) on the bands going to the Greenawalt pans.

The coke breeze used in sintering is 4.5%. The sinter is the best I have seen and is charged to the furnaces in good-sized pieces; the percentage of fines returned to the pans is very small.

The iron content of the burden is about 58% and the analysis of the iron about 0.2% silicon, 1% manganese, 1.8% phosphorus, and 0.03–0.04% sulphur. Coke consumption is only 650–750 kg. per metric ton.

CORRESPONDENCE.

Mr. R. P. TOWNDROW (Cargo Fleet Iron Co., Ltd., Middlesbrough) wrote: The interesting paper which Dr. Saunders has presented has given a scientific explanation of the mechanism of the sintering process. It has shown clearly that under the correct conditions of temperature and deoxidation it is possible to produce iron-oxide sinters at a temperature which is low compared with that obtaining in most commercial processes, the product being of good mechanical strength and of much higher porosity than the normal run of commercial sinters.

These results have been obtained by separating the functions of heating and deoxidation in a manner which is not possible with types of sintering machines at present in general use. It is therefore of interest to examine the modifications which may be necessary to reproduce this technique on large-scale operations.

In the first place, it appears that some distinction must be drawn between the sintering of mixtures consisting mainly of rich-ore fines and

* *The Iron and Steel Institute, 1944, Special Report No. 30, p. 59.*

those containing mainly native-ore fines. In the first case, owing to the relatively small proportion of slag-forming material present, there exists a much greater range of temperature within which sintering can take place without the formation of large amounts of slag.

In the second case, an abundance of slag-forming material is present, intimately mixed with the iron-oxide particles, and the temperature range between sintering and slagging is correspondingly reduced.

We are of the opinion that the most important single factor in securing the necessary control is that of fuel distribution and fuel size. During sintering we have the condition of a particle of incandescent breeze, at a temperature far in excess of that required for sintering, surrounded by material at a temperature which progressively decreases with distance until the material comes under the influence of the next particle of breeze. There can be only a portion of this material, therefore, at the correct sintering temperature. It follows that the smaller the fuel particles, the more material there is at the correct temperature, and the less fuel is required to achieve that temperature.

In round figures, when using breeze of $\frac{1}{2}$ -in. size, in which the proportion of $\frac{1}{2}$ - to $\frac{1}{4}$ -in. is normally about 25%, 10% of fuel is necessary to provide adequate distribution. This results in a hot sinter, and, at the same time, a considerable amount of unsintered material due to bad heat distribution. The depth of the high-temperature zone is about 5 in., which at the normal rate of sintering means that combustion will continue to occur in about 30% of the sintered mass for some 8 or 9 min. after the temperature front has reached the bottom of the pan. This has the effect of slowing down the sintering rate after about half the pan has sintered, owing first to the continuing reduction of porosity in the hot mass, and secondly, to the wastage of oxygen used in burning the excess fuel at a point where it is neither necessary nor desirable.

When breeze of $\frac{1}{8}$ -in. size is used the depth of the combustion zone is reduced to about 2 in., and it is possible to reduce the fuel to 5 or 6%, with the result that the sintering rate is increased and the product is properly cooled by the time the pan is ready to tip.

Even under these conditions, however, an examination of the product shows that where the sinter is strong enough to withstand handling without excessive breakage, a fair amount of slagging has taken place, and if the breeze is reduced still further, the sinter, while free from slag, is readily broken up on impact to a size which would not be suitable for the blast-furnace. This appears to indicate a deficiency in iron-oxide bond under the conditions obtaining, and an examination of the time-temperature curve in the pan provides an explanation of this. Curves taken with a thermocouple $8\frac{1}{2}$ in. below the surface of the pan all show a characteristic shape. The temperature rises about 100°C . in the first 10–15 min., then rises abruptly in less than 1 min. to the maximum, which is usually between 1200° and 1300°C . It appears therefore that there is not sufficient time during which the material is heated to a temperature at which reduction can take place, before it is subjected to the melting temperature. This fact may account for part of the usefulness of returned fines in the process, inasmuch as these fines provide a ready-made source of ferrous oxide.

It would appear, therefore, that, when sintering lean ores by any down-draft process at present in use, it is a matter of extreme difficulty to produce an iron-oxide bond preferentially to a ceramic bond, although by adequate sizing of the fuel it should be possible to avoid the production of ferrous silicate. In view of the relatively low temperatures at which native ores melt in a reducing atmosphere, the employment of the ceramic bond in sintering may well be less disadvantageous than is generally held to be

the case. In any event, we are of the opinion that adequate strength is an essential requirement in sinter, because, if it breaks down to fines on handling, the whole object of the process is lost, and very serious derangements of the furnace operation will follow the use of dusty and fine sinter.

Full agreement is expressed with the statement that one advantage of the use of sinter in the burden is due to the fact that sinters normally show very little impregnation by carbon. In fact, provided that their physical condition is satisfactory, this freedom from carbon impregnation would appear to be their outstanding advantage in maintaining the essential permeability of the burden. Swedish ores, which are of low reducibility and are poor carbon impregnators, have been shown by experience in basic-iron production to behave in a similar manner to sinters in keeping the burden open.

AUTHORS' REPLY.

The AUTHORS wrote in reply: We desire to emphasise that the conditions referred to in connection with Figs. 5, 6 and 7 could not in any way be regarded as artificial. There is a very much smaller temperature range for satisfactory sintering with fluxing ores, especially if the carbon is kept low, and therefore less latitude in processing. Details of sinter strength correlated with fuel consumptions would be most valuable, and the suggestion of systematic records is heartily endorsed.

We are in close agreement with Mr. Towndrow's comments on fuel and consider that some of the difficulties to which he makes reference could be minimised by attention to draft control in addition to sizing of the materials. The addition of return fines should as far as possible be eliminated; it is certainly illogical to sinter fines of one material to produce fines of another.

SOME DESIGN AND OPERATING FEATURES OF A NEW BLOOMING MILL.*

By G. A. V. RUSSELL,† WH.Ex., AND G. W. FOX (THE UNITED STEEL COMPANIES, LTD., MESSRS STEEL, PEECH AND TOZER BRANCH, SHEFFIELD).

(Figs. 1 and 6 = Plates XXXIV. and XXXV.)

SYNOPSIS.

The paper discusses the design and operating features of a new 43-in. reversing blooming-mill installation which has replaced a lighter mill at the Templeborough plant of The United Steel Companies, Ltd. Allusion is first made to the general layout of the plant and then the mechanical design of the new mill is considered, the mill train, main tables, and manipulator being dealt with in turn. The roll design and rolling practice adopted are next described, and some results of actual performance are included. The paper concludes with reference to certain improved auxiliaries which have been installed, such as a four-way hot-bloom deseamer and a new type of preheating pit furnace for ingots.

It was recently decided to replace the existing 40-in. blooming mill at the Templeborough plant of the Steel, Peech and Tozer Branch of The United Steel Companies, Ltd., by a heavier unit and to re-install the old mill, after reconditioning, at another works. This paper describes some design and operating features of the new installation.

As no alternative blooming facilities existed, it was imperative that the period of shut-down for dismantling the old plant and installing the new should be reduced to a minimum. Study of the layout showed conclusively that the only location suitable for the new mill was that occupied by the old. This limited the amount of preparatory work that could be done before the change-over and influenced the design of the new plant, as it was necessary to utilize as much as possible of the existing heavy foundations.

LAYOUT OF THE PLANT.

Fig. 1(a) shows the general layout of the old plant and Fig. 1(b) that of the new mill and ancillary facilities. Perusal of these will show that the mill building proper has been extended and the rail-track arrangements in its vicinity have been improved. Better scale-handling arrangements have also been added.

The mill is served by an installation of sixteen double-chamber, recuperative soaking pits arranged in two rows on either side of the chariot track and ingot-car reception roads. In addition, there is a pair of pre-heating pits which have been recently installed for alloy and high-carbon steels. Each soaker hole is 6 ft. 3 in. \times 13 ft., and thus the aggregate hearth area is about 2400 sq. ft., which is a liberal figure for British practice. The average track time for heats delivered from the open-hearth is 3.25 hr. and the normal heating times are roughly twice the track time. Charges of cold ingots are heated in 7-9 hr.

* Received March 6, 1945.

† Now South Durham Steel and Iron Co., Ltd., Middlesbrough.

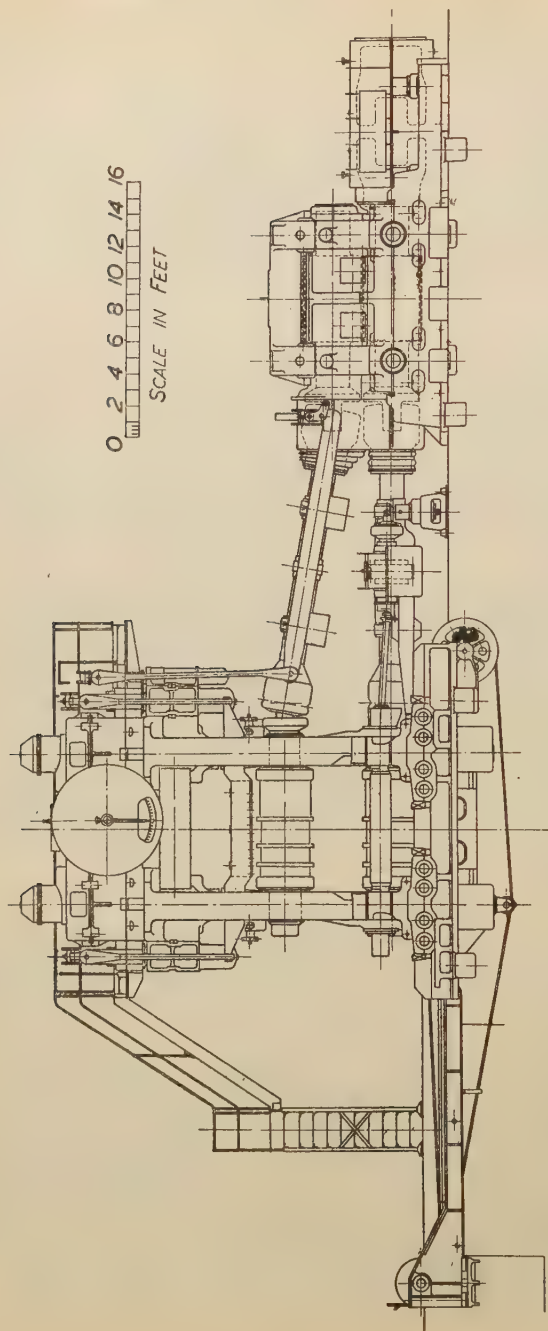


FIG. 2A (see Figs. 2B and 2C).—Arrangement of Mill Train: Side Elevation.

Another reference to Fig. 1(b) will show that an extension approach table has been incorporated in the new mill, with the object of enabling the mill to be fed in the event of both the chariot and the mill-end soaking-pit crane being out of action simultaneously.

MECHANICAL DESIGN OF THE MILL.

The Mill Train.

An idea of the design features of the new plant will be obtained from the general arrangements of the mill train, and of the tables and manipulator reproduced in Figs. 2 and 3, respectively. The existing 256 metre-ton, maximum-torque-capacity, double-armature, reversing motor which drove the old mill is connected to the new 43-in. pinion stand through a leading

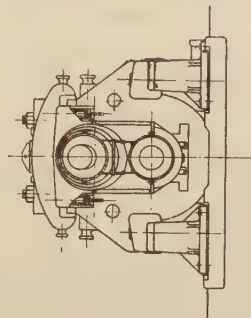


Fig. 2c (see Figs. 2A and 2B).—
Arrangement of Mill Train:
End View of Pinion Stand
(looking in direction of drive).

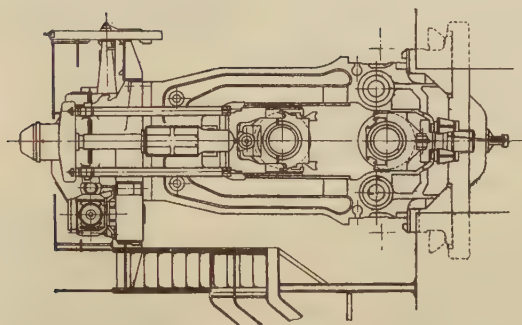


Fig. 2b (see Figs. 2A and 2c).—
Arrangement of Mill Train:
End View of Roll Stand.

spindle of the jaw-and-palm-end type, totally enclosed and spray lubricated. The slab-connecting element of the coupling is arranged for adjustment to take up wear—a new feature for which patent protection has been obtained.* The pinion stand is made in two sections and is firmly anchored to heavy box-section beds resting on the foundations. The pinions of 63-in. face width are of compound construction. The rims of 0.45% carbon, 0.6% manganese steel with 35, 20° pressure angle, continuous double helical teeth of 3.859 in. pitch are shrunk on to the shafts, which are 0.3% carbon steel forgings. The pinion necks revolve in white-metal-lined bearings, 25 in. dia. \times 33½ in. long, continuously lubricated.

The mill spindles are steel forgings and are of the jaw-and-palm-end type, 17 ft. 3 in. from centre to centre of the driving elements. At the pinion end they are totally enclosed and spray lubricated. Both spindles are duplicates and each is hydraulically balanced to facilitate roll changing.

The roll housings are one-piece steel castings having a minimum post

* British Patent No. 546,164, C. S. Tate and Davy and United Engineering Co., Ltd.
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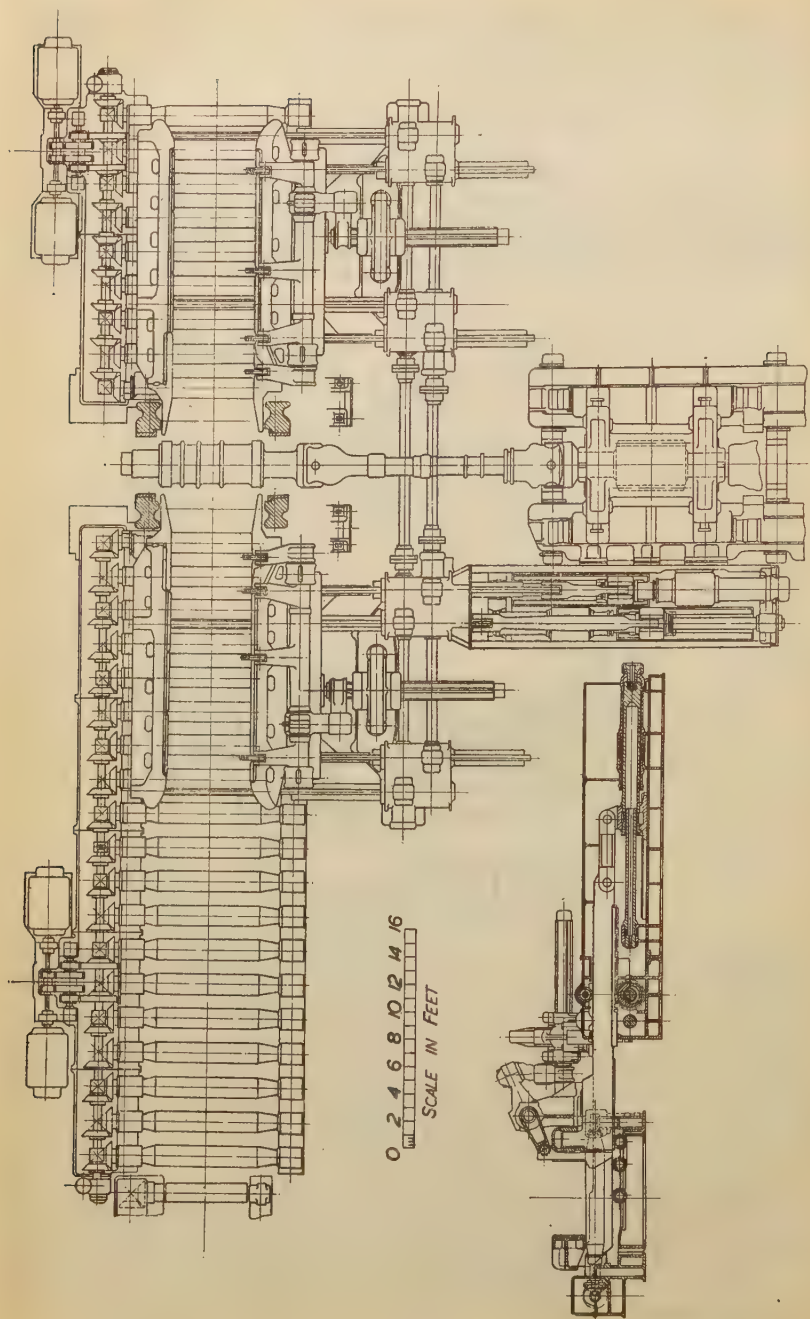


Fig. 3.—Arrangement of Main Tables and Manipulator.

area of 550 sq. in. and weigh about 56 tons each. The flat housing feet are made extra long and wide and are secured by shrunk hoops and wedges to massive, cast-steel, box-section bed-plates which rest on the mill foundations and are further reinforced by heavy cast-steel tie-pieces.

The screw-down mechanism is of the spur and bevel gear type and is of rather novel layout. It is housed in a rigid steel casting which also forms the principal top tie of the roll-stand assembly. Power is provided by two 120-h.p., variable-voltage, D.C. motors, Ward-Leonard controlled, and is transmitted to the 14-in.-dia. mill screws through two reductions of

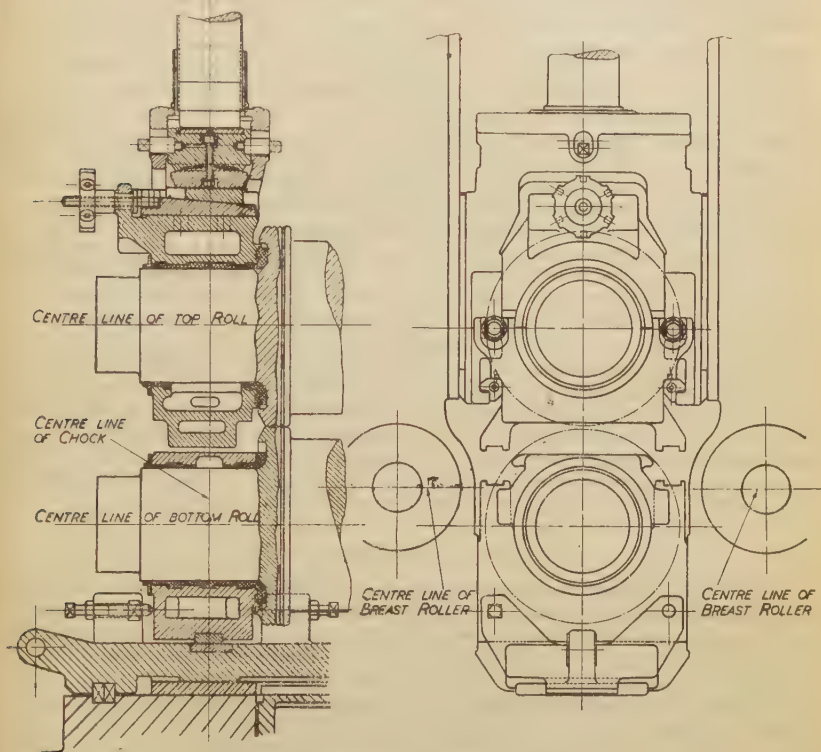


FIG. 4.—Arrangement of Mill Chocks.

spur gearing and then by bevel gears. The driven vertical bevels are mounted on long hollow sleeves having internal longitudinal grooves to engage with the splines, of which there are three at the upper end of each screw. The layout of gearing is quite symmetrical, so that any wear will be uniform and not disturb the tooth alignment. The whole mechanism is totally enclosed and continuously lubricated. The screws work in telescopic enclosures and the long phosphor-bronze nuts are lubricated by a special grease-lubricating system to permit of the employment of extreme-pressure grease. The maximum screwing speed is 220 in./min.

The index gear is driven from the central cross shaft of the screw-down mechanism and is arranged in the form of a sub-assembly so that its

alignment is assured. In place of the usual revolving finger and fixed dial, the latter rotates and the finger remains stationary. This makes the "clock" indications very easy to read. In addition to the dial indications, the roll opening readings are repeated through a Selsyn transmission on a drum indicator situated in the mill pulpit.

The roll-neck bearings are unusual, in that they are self-aligning to reduce wear to a minimum. Their arrangement will be seen from Fig. 4. They are comparatively thinly lined with white metal and are continuously lubricated by grease fed under pressure into scoops in the low-pressure region of the bearing surface. Both direct and indirect water-cooling facilities are incorporated in the chock design. The top-roll rider chocks are faced with hard bronze liners where they are in contact with the housing-window wearing plates. The top roll is balanced by two vertical cylinders, mounted on the outer face of the roll housings, and suspension rods, depending from the ram crossheads, sustain the roll carrier to which the chock hanger bolts are attached.

Roll changing is effected by the simultaneous axial withdrawal of both rolls and their chocks out of the roll stand by means of a sledge upon which the bottom-roll main chocks are mounted. This can be drawn out and pulled back into position by the shop crane by means of wire ropes and suitable snatch blocks. A complete roll change requires about 2 hr.

The breast rollers are nickel-chrome steel forgings, 16 in. dia., arranged for axial withdrawal. The water-cooled bodies of the grease-lubricated bearings are rigidly mounted in tapered holes bored in the mill housings. The breast-roller drive is new and has been patented.* Power is derived from the bottom mill spindle by means of a split gear clamped to it. On either side this drives an idler pinion and a hollow pinion. The latter embodies a slipping clutch element, the driven portion of which, passing through the hollow stem, connects with the driving end of the breast roller by a short universal spindle. The gearing is enclosed in an oil-tight, spray-lubricated gear-box, formed with the bottom spindle suspension rig. This drive assures in a simple manner that the breast rollers rotate at the correct speed and direction and are thus protected from abuse.

The Main Tables.

The main table and approach rollers are pitched at 2 ft. 6 in. centres. The tables are of very heavy all-steel construction with cast-steel framing and 18-in. dia. rollers of forged steel. The main table roller bearings are 9½ in. dia. and 15 in. long. Considerable refinement of detail has been embodied in the bearing design to exclude scale and dirt and prevent loss of oil. The white-metal-lined roller and line shaft bearings are continuously lubricated with the exhaust oil serving as bath lubrication for the gear teeth. The oil is distributed to the various bearings through rectangular ducts formed in the table frame castings. The mitre gears are steel forgings with cut teeth. The axial thrust on the line shafts is taken by ball bearings mounted in housings which can be moved axially for the purpose of disengaging the gears when it is desired to change a roller.

Each main table is driven through symmetrically arranged, double-reduction gearing from two 100-h.p., series-wound, D.C. motors which are connected to the pinion shaft by flexible couplings.

The Manipulator.

The mill is equipped with a side-guard type manipulator provided with lifting fingers on both sides of the rolls. The manipulator is hydraulically

* British Patent No. 541,026, G. A. V. Russell and The United Steel Companies, Ltd.

operated and the driving mechanism for both sets of side-guards is located on the motor side of the mill. This disposition reduces the floor space required and improves the accessibility of the table line shaft gearing in the vicinity of the manipulator. The side-guards are box-section steel castings having wearing plates arranged with air-cooling spaces behind them on the working faces. Each rests on the upturned ends of two heavy forged-steel slab-section beams, to which the cut racks are very solidly attached. The latter engage with shrouded cut pinions on the through squaring shafts. Both rack and pinion shrouds are renewable. Each shaft is actuated by an opposed telescopic cylinder hydraulic unit, so arranged that the side-guards open under constant pressure and close under manual control. The designed side-guard pressure is 24 tons. Each tilting mechanism comprises four lifting fingers, working in slots in the face of the side-guard. These are actuated by levers formed with a hollow cast-steel rocking shaft which is mounted in a special bracket attached directly to the appropriate pair of rack beams. Each rocking shaft is worked by a stationary hydraulic unit with vertical rams through the intermediary of a hollow spline shaft anchored in the rocking shaft bracket and thus moving with the side-guard. The spline shaft carries a lever arm at the side-guard end which is coupled to the rocking shaft operating lever by a universal link: this is necessary since the motion has to be transmitted through 90°. The splines engage with grooves cut in the hole through the boss of the rocking lever which is actuated by push rods from the rams of the operating cylinders. The whole tilting mechanism is so designed that no binding can occur when alignment alters as a result of wear, expansion or any other cause.

The manipulator is very speedy yet precise in action. This is due in part to the provision of large relay-operated controlling valves. The relay cylinders are controlled from the mill pulpit by small, manually operated, balanced, mitre-seated valves, those for the side-guards being worked by hand levers whilst back and front tilting mechanism valves are pedal operated.

All the working parts of the mill-train tables and manipulator are continuously lubricated from a central lubricating house which contains two oil-circulating systems and several Tecalimit grease-distribution systems. Each oil system is designed to circulate about 25 gal./min. and the main return oil storage tanks can accommodate some 2000 gal. Duplicate pumps are provided for each system, together with approved filtering, settling, oil-temperature controlling and warming apparatus. One system supplies the mill pinions, the main coupling, and the screw-down gear, while the second serves the approach and main ingoing and outgoing tables. The other working parts are grease lubricated with separate distributing lines for the larger bearings and sliding surfaces such as the main screw boxes, the roll necks and top-chock window slides, the spindle carrier bearings and breast roller bearings. The other bearings, such as those for the manipulator rack shafts, are group-fed from multipoint distributors.

OPERATION OF THE MILL.

The mill is controlled by three operators, who are located in a pulpit spanning the front main table. The roller operates the screw-down mechanism and the main tables. The second man drives the main motor and works the approach table, while the third operator controls the manipulator. Working conditions in the pulpit are improved by the provision of air conditioning.

The tilting fingers both back and front of the mill were provided with the object of turning over the ingots after the first pass, a procedure which

the authors have long believed advantageous from the standpoint of quality. This provision also affords greater latitude in laying out drafting schedules.

The bulk of the ingots rolled are of two sizes: (i) $3\frac{1}{2}$ ton, $22\frac{1}{2}$ in. square, and (ii) $4\frac{1}{2}$ ton, 25 in. square. The latter are teemed into three types of moulds: (i) a semi-closed top, small-end-up one for rimming and semi-killed steels, (ii) a small-end-up mould with a semi-permanent brick top, and (iii) a wide-end-up mould with loose feeder head. All these ingots have corrugated convex flanks and those cast small-end-up are

TABLE I.—Normal Drafting Schedules (Ingot 24×24 in.).

Pass.	Gate. In.	Draft. In.	Approximate Size Leaving Pass. In.	Reduction of Area. %.	Manipulation.
A—13-Pass Schedule.					
1	25	3	21×24	8.8	Turn
2	25	3	21×21	16.0	...
3	25	3	18×21	14.2	...
4	25	3	15×21	16.7	Turn
5	$15\frac{1}{2}$	3	$18 \times 15\frac{1}{2}$	11.7	...
6	$15\frac{1}{2}$	3	$15 \times 15\frac{1}{2}$	16.6	Turn
7	$15\frac{1}{2}$	$2\frac{1}{2}$	$12\frac{1}{2} \times 15\frac{1}{2}$	16.4	...
8	$15\frac{1}{2}$	3	$9\frac{1}{2} \times 15\frac{1}{2}$	24.1	Turn
9	10	3	$12\frac{1}{2} \times 10$	17.0	...
10	10	3	9×10	22.2	Turn
11	10	$2\frac{3}{4}$	$7\frac{1}{4} \times 10$	23.7	Turn
12	$7\frac{3}{8}$	$2\frac{7}{8}$	$7\frac{1}{8} \times 7\frac{3}{8}$	21.1	Turn
13	$7\frac{3}{8}$	$\frac{1}{8}$	$7\frac{1}{4} \times 7\frac{1}{4}$	0.4	...
B—15-Pass Schedule.					
1	25	$2\frac{1}{2}$	$21\frac{1}{2} \times 24$	6.6	Turn
2	25	$2\frac{1}{2}$	$21\frac{1}{2} \times 21\frac{1}{2}$	14.7	...
3	25	$2\frac{1}{2}$	$19 \times 21\frac{1}{2}$	11.4	Turn
4	25	$2\frac{1}{2}$	19×19	11.7	...
5	25	2	17×19	10.2	...
6	25	2	15×19	21.1	Turn
7	$15\frac{1}{2}$	2	$17 \times 15\frac{1}{2}$	7.4	...
8	$15\frac{1}{2}$	2	$15 \times 15\frac{1}{2}$	12.1	Turn
9	$15\frac{1}{2}$	$2\frac{1}{4}$	$12\frac{3}{4} \times 15\frac{1}{2}$	15.1	...
10	$15\frac{1}{2}$	$2\frac{3}{4}$	$10 \times 15\frac{1}{2}$	16.2	Turn
11	10	$2\frac{3}{8}$	13×10	16.1	...
12	10	3	10×10	23.0	Turn
13	10	$2\frac{3}{8}$	$7\frac{1}{4} \times 10$	27.5	Turn
14	$7\frac{3}{8}$	$2\frac{3}{4}$	$7\frac{1}{4} \times 7\frac{3}{8}$	26.3	Turn
15	$7\frac{3}{8}$	$\frac{1}{8}$	$7\frac{1}{4} \times 7\frac{1}{4}$	2.3	...

designed with a minimum taper. At present, feeder-head ingots make up about 50% of the production.

Particulars of the normal drafting practice on the large ingots are given in Table I.

It will be noted that they are reduced to the standard $7\frac{1}{4} \times 7\frac{1}{4}$ in. bloom for feeding the 21-18 in. continuous billet mill in 13 or 15 passes. This represents mean reductions of 16.8 and 14.7% per pass respectively. If the ingots are not thoroughly soaked the two extra passes are taken. The following data give an idea of the average rolling and manipulative times when rolling the two sizes of ingot above mentioned; modifications are in hand further to speed-up the tilting mechanism and will result in a slight reduction of the manipulative time.

Analysis of Rolling and Manipulative Times.

25 in. square ingots to $7\frac{1}{2} \times 7\frac{1}{2}$ in. blooms in 13 passes :

Total time	1.56 min.	= 100%
Time in rolls	0.76 "	= 49%
Manipulative time	0.80 "	= 51%

25 in. square ingots to $7\frac{1}{2} \times 7\frac{1}{2}$ in. blooms in 15 passes :

Total time	1.73 min.	= 100%
Time in rolls	0.86 "	= 50%
Manipulative time	0.87 "	= 50%

22 $\frac{1}{2}$ in. square ingots to $7\frac{1}{2} \times 7\frac{1}{2}$ in. blooms in 13 passes :

Total time	1.48 min.	= 100%
Time in rolls	0.70 "	= 47%
Manipulative time	0.78 "	= 53%

THE ROLLS.

The arrangement and proportions of the roll gating have been devised to favour speedy working and minimize damage to the steel. Fig. 5(b)

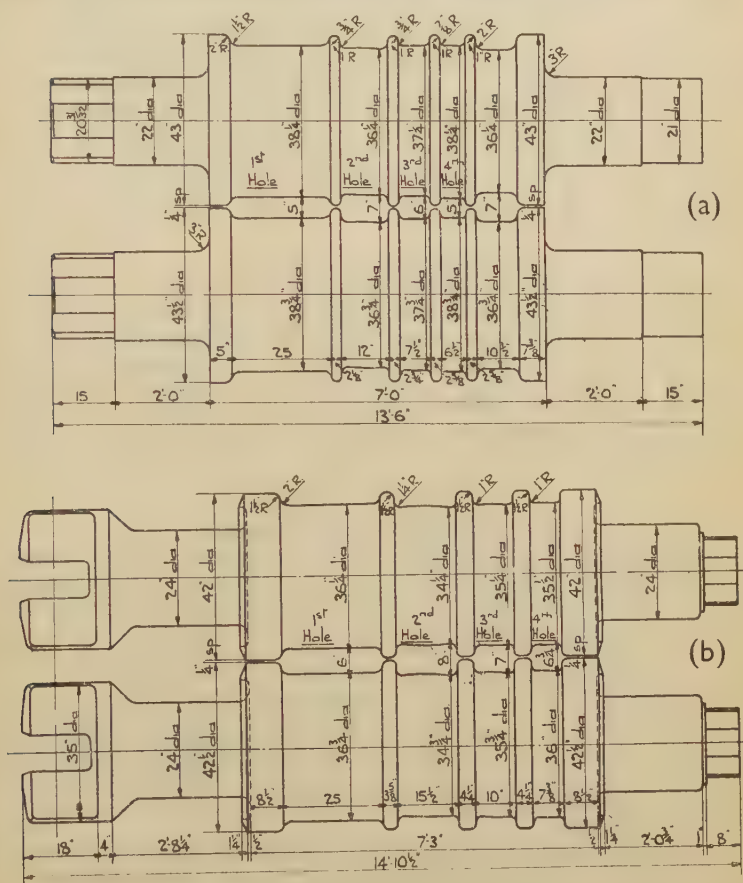


FIG. 5.—Arrangement of Roll Gating. (a) Old rolls. (b) New rolls.

shows the arrangement of roll gates, which may be compared with that used previously shown in Fig. 5(a). Attention may be drawn to the relatively wide second hole. This is advantageous in affording more corner support to the bloom than usual, when the width of the second gate is about half that of the ingot hole. The heavy end collars afford clearance for much more substantial side-guard extensions than are normally found in blooming mills whose manipulators embody these extensions.

Forged-steel rolls with integral driving ends are employed. This type of roll, which is made on the works, was employed in the old plant. Previously, when a medium (0.5%) carbon steel was used, such rolls would turn out about 25,000 tons between dressings and would then require the removal of about $\frac{3}{4}$ in. off the diameter to clean up at the collars. The resultant average roll life was about 240,000 tons. With the object of decreasing the rate of side wear on the collars, one of the authors developed a method of surfacing the collar faces with a hard alloy deposited by welding. This technique, for which patent protection is being sought, has given promising results. As a result of it, the tonnage between dressings has increased to 45,000–50,000 tons and then the rolls will clean up satisfactorily with only some $\frac{1}{4}$ – $\frac{3}{8}$ in. off the diameter. Roll lives of upwards of 500,000 tons are confidently expected. Because of the hard-surfacing of the collars, it is feasible to employ a softer steel for the roll forgings. The carbon content of the rolls in current use is about 0.35–0.4%, with corresponding increase in ductility which should virtually eliminate roll breakages. In addition to the much reduced rate of wear and correspondingly longer roll life, the delivery of a more regular section from the blooming mill is an important operating advantage resulting from this development, as pass widths can be maintained at virtually nominal dimensions.

PERFORMANCE OF THE MILL.

An idea of the order of performance obtained from the mill soon after its installation will be gathered from Table II. Here the essential production data for 10 consecutive weeks' operation, terminating at the week ending December 23, 1944, are recorded. The tonnage and delay figures are clearly susceptible of betterment and provide a stimulus to reach higher levels of output. The relationships between net current consumption and tonnage and the proportion of cold and black-hot ingot charging are also discernible in the figures.

AUXILIARY FEATURES.

Four-Way Hot-Bloom Deseamer.

In addition to the mill proper, the reconstruction scheme embraced certain new auxiliary facilities. One of the most important of these is a Linde, four-way, hot-deseaming machine for hot-scarfing blooms leaving the mill. This unit replaced a two-way machine installed in 1940. The latter necessitated taking two passes and turning up the bloom between them. The new deseamer is equipped with efficient fume-removal and swarf-disposal facilities. Swarf is washed away from a sump under the machine and conveyed to a large settling basin in the adjoining bloom yard bay; thence it is reclaimed and loaded into wagons by grab bucket or magnet. The acetylene gas supply for the machine is derived from dissolved gas in cylinders which are coupled in banks to the pressure-reducing and distributing system as required. Oxygen is furnished from a liquid-oxygen plant.

Hot-scarfing is useful for such qualities as axle, shell and drop-stamping steels, and Ledloy and free-cutting steels of the high-sulphur type, as it reduces overall conditioning costs. At present the average tonnage hot-

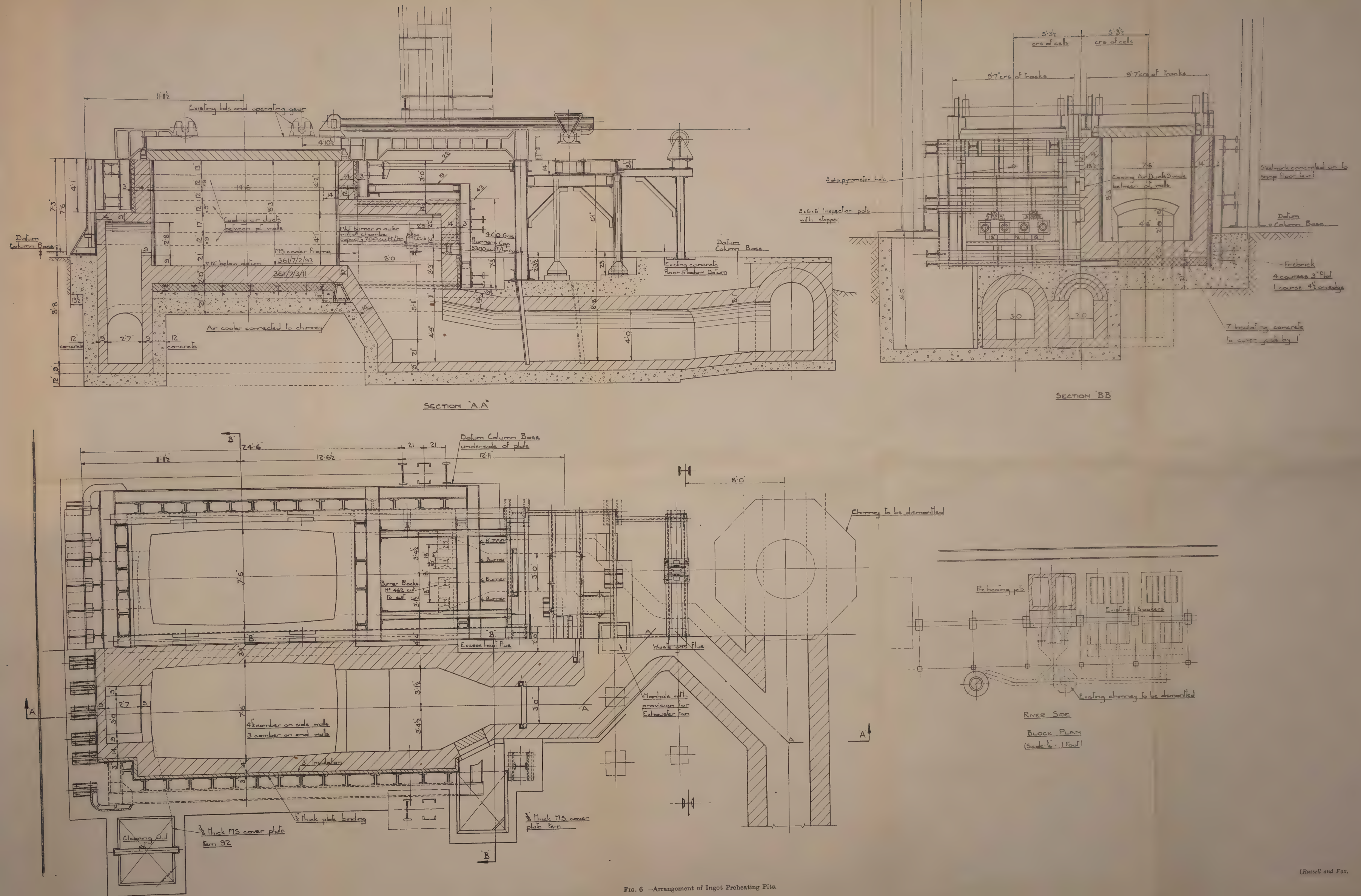


TABLE II.—*Typical Performance Data for a Ten-Week Period.*

Week Ending (1944).	Gross Time Worked.*		Stoppages.†			Net Ingot Weight Rolled, Tons.			Current Consumption, kWh. per ton.		Average Weight of Ingots, Cwt.	Average Number Rolled per Net Hr.	Percentage of Ingots Heated from :	
	Hr.	Min.	Time Lost.		Per- centage of Gross Time.	Week.	Per Gross Hr.	Per Net Hr.	Gross. (Mill and Auxili- aries.‡)	Net. (Main Roll Drive only.)			Cold.	Black Heat.
			Hr.	Min.										
Oct. 21	129	20	16	10	12.5	11,809	91.31	104.5	20.31	16.55	79.61	26.55	18.97	28.08
" 28	129	15	13	38	10.55	13,374	103.47	115.6	19.24	16.46	79.86	29.14	25.11	19.40
Nov. 4	129	16	18	08	14.03	13,388	103.57	120.8	19.28	16.51	78.75	30.63	27.78	21.15
" 11	129	20	18	44	14.48	11,470	88.69	103.7	19.81	16.45	80.00	26.21	18.18	30.83
" 18	129	20	13	32	10.46	12,343	95.44	106.5	19.25	16.05	78.91	27.34	20.90	29.45
" 25	129	16	17	27	13.50	11,993	92.78	107.2	19.01	16.16	78.13	28.13	24.33	32.58
Dec. 2	129	20	13	24	10.36	12,850	99.36	110.8	18.77	15.82	78.44	28.89	26.48	23.38
" 9	128	57	14	44	11.30	13,603	105.49	119.1	18.72	15.85	78.77	30.73	30.54	29.55
" 16	129	14	19	29	15.08	13,774	106.58	127.2	18.74	16.06	79.55	31.68	28.74	23.71
" 23	128	50	21	55	17.01	12,411	96.33	116.0	19.91	16.96	78.13	30.70	29.79	23.37

* Excluding meal times.

† Including any mechanical and electrical breakdowns of the blooming mill proper or any other unit of plant which precludes the blooming mill from rolling; also heating and manipulative delays and delays due to causes external to the Blooming Mill Dept.

‡ In addition to the main roll drive and blooming mill auxiliaries, this includes current for ingot chariot, hot descaler plant, crop and cutting-up shears, bloom transfer, scrap conveyor, shear front and back tables, bloom bank, mill cranes, &c.

scarfed per week is approximately 5000 tons. The yield loss runs 1.5% and acetylene and oxygen consumptions average 3.8 cu. ft. and 90 cu. ft./ton respectively.

Ingot Preheating Furnace.

Another new item of plant is an ingot preheating pit fired with coke-oven gas. As this is of very simple design and consequently cheap to build, a few particulars may be of interest. Its essential features will be apparent from Fig. 6. The two ingot chambers are 14 ft. 6 in. \times 7 ft. 0 in. and 10 ft. deep—a size which enables the covers and cover-operating mechanism to be interchangeable with those of the ordinary pits. Each chamber can take between about 40 and 50 tons of ingots. Behind the ingot chambers are relatively large combustion chambers, each with four high-pressure gas burners. At the other end the ingot chambers are coupled by a connecting flue. The principle of operation may be designated as reversing by charges. Assuming both holes to be charged, the burners of the combustion chamber associated with the hole containing the ingots which has been charged longest are on. The products of combustion after circulating through the spaces between the ingots in this chamber, flow into the second chamber and exhaust into the combustion chamber, and out to the chimney flue, past a reversing damper. When the first charge is drawn the direction of combustion is reversed and the empty chamber is recharged with cold stock. With this method of working the rate of heating is quite gradual and owing to the long flame travel reasonable economy can be achieved with the simplest construction; no recuperators are fitted. This unit is capable of heating about 1500 tons of cold ingots per week to 800° C., with a heat consumption of about 1.2×10^6 B.Th.U./ton.

INSTALLATION OF THE MILL.

In conclusion, allusion may be made to the dismantling of the old mill and the installation of the new plant. The former rolled up to 10 p.m. on June 23, 1944, and trial ingots went through the new mill at 2 p.m. on July 21. The old plant, which weighed about 900 tons, and the new equipment to replace it, which weighed upwards of 1000 tons, were changed, and all the requisite alterations to foundations, pipework, wiring, &c., were carried out. Time was saved by the unit erection of as much of the new equipment as possible, *e.g.*, the main roller tables were placed in position complete in sections weighing about 90–100 tons each. Because of the intention to re-utilize the old mill, it was dismantled with more care than if it were being scrapped. The principal shut-down was preceded by a shorter stoppage of 2½ weeks six months previously, during which the old pinion-housing and main coupling were replaced by the corresponding new equipment, and at the same time certain temporary provisions, which permitted this change to be made, had to be carried out to the old manipulator drive and roll stand.

ACKNOWLEDGMENTS.

The authors would like to express their appreciation of the help and co-operation given by Mr. A. Poole, Chief Engineer, The Davy and United Engineering Company, Ltd., and his staff, who furnished the main portion of the mechanical equipment. They also desire to express their indebtedness to their colleagues, particularly Messrs. J. W. Russell, V. Watkins, D. Pearson, A. Calvert, and R. Brunyee, for assistance in designing, installing, and operating the plant, and to Mr. Gerald Steel, Assistant Managing Director of The United Steel Companies, Ltd., for permission to publish this paper.

DISCUSSION.

Mr. Fox, in presenting the paper, said with regard to the performance of the mill (p. 328 P) : I have the figures for more recent dates. From 1st September to 3rd November of this year (1945) the total is 133,849 tons, or a weekly average of 13,384 net ingot tons, as compared with a weekly average of 12,701 in the previous ten weeks. This increase of 683 tons has been achieved in spite of the reduced average ingot weight of about 10-12 cwt., due to a large proportion of bought ingots.

Dr. C. H. DESCH, F.R.S. (President-Elect, London) : We are greatly indebted to the authors of this paper for giving us such a full account of a mill, the design and operation of which have obviously been very carefully thought out, so that the information given in the paper should be of great value to those who are concerned afterwards with the erection of new mills. Now that the Rolling Mill Research Committee is very active, the provision of such information as is given here will be of value to the whole industry.

I wish to refer to only a few small points in the paper.

The description of the hardening of those portions of the roll on which the really heavy wear comes interested me greatly. One would like a considerable hardness in the rolls if it were not for the danger of brittleness. The means given in the paper overcomes that difficulty. The parts on which the really serious wear comes are hardened, and one can use a comparatively soft steel for the roll forging, leading necessarily to a diminished breakage. That is an important development, of interest to all concerned with the construction of mills.

The four-way hot-bloom descaling machine is of very great interest. It is effective and it is a rather spectacular piece of plant, but it makes one think about the preparation of ingots and blooms. By using this method we get rid of defects from the surface. It involves a yield loss of 1.5% and a consumption of considerable volumes of both oxygen and acetylene. I have no doubt that it proves quite economical, but it makes us ask the question : Should not rather more care be given than is given now in many works to the preparation of the surface of the ingots? We often find that ingots come out with defects on the surface which ought not to be there. If we took sufficient care about the material of the moulds (that is a matter which is under discussion at present) and in the dressing of the moulds, and, more particularly, in looking after the moulds, I believe we could reduce those surface defects to such an extent that we should not need this elaborate descaling process. It is really a form of penance for some of our previous sins. However, we know that the descaling plant described in the paper works very well indeed.

I should like to ask one question about the bearings. I notice that white-metal-lined bearings are used. I wonder whether plastic bearings have been considered, and, if so, whether the authors could give us their views on the relative value of white-metal and plastic bearings on mills of this type.

Dr. J. H. WHITELEY (Consett Iron Co., Ltd., Consett, Co. Durham) : Dr. Desch's remarks on descaling have reminded me of a method of treating blooms for rails which has been patented by the Lackawanna Steel Co. In a pamphlet describing the process it is stated that the hot bloom is subjected on top and bottom surfaces to cutting action from

teeth on two opposed rotating saw discs just after it comes from the cogging mill. In this way the surface is quickly removed from each face to a depth of $\frac{1}{8}$ in. or more. Have the authors had any experience of this method?

AUTHORS' REPLY

The AUTHORS, writing in reply, thanked Dr. Desch for his appreciative comments. They were conscious that any plant such as that described in the paper represented a compromise, which was perhaps inevitable, between the claims of different requirements, *e.g.*, operating considerations, purely engineering features, site restrictions, &c. In this sense, as Dr. Desch indicated, the paper might be useful when considering the application of research work in actual practice, as the latter usually imposed limitations upon the degree to which it was advantageous to pursue any given ideal if the best overall results were desired.

The hard facing of the sides of the roll collars originated from an attempt to salvage a pair of plate-mill rolls which had developed flaws in forging. It was found that the sound portions could be utilized for the Templeborough cogging mill. As they were only of 0.33% carbon steel it was felt that to prevent an undue rate of collar wear it would be worth trying to reduce this by surfacing the collars with Stellite. This proved successful, and the rolls gave the best life so far, *i.e.*, 320,000 tons. The advantage of width control due to the slower rate of collar wear was most apparent. Needless to add, the cost of collar surfacing had been greatly reduced from that first attempt and was now only about £50 per pair.

The adoption of fabric roll-neck bearings was given much consideration, but they were ruled out on account of inadequate water supply, which was essential for their successful use. It should be noted that the positively lubricated, self-aligning metallic bearings showed just as low a power consumption as was obtained with fabric bearings in similar duty, and it was doubtful whether the latter would show any lower overall cost. They would, however, still offer the advantage of cleanliness.

Dr. Desch rightly drew attention to the fact that an appliance like the hot deseamer should be virtually unnecessary with better standards of ingot teeming, mould conditioning and possibly steelmaking, and that it entailed an inevitable yield loss of about 1.5%. As things were, however, even in a plant where technical control of these phases of steel production was more rigorous than usual, the authors considered that the availability of this equipment and its judicious use lowered conditioning costs for those classes of steel specially prone to surface defects. The hot deseamer, whilst not the only hot-conditioning process available, was one that suited conditions in the Templeborough plant, where the possible alternative of wash-heating full-weight blooms would present considerable difficulties. It should be remembered that the yield loss with any hot-conditioning process was about the same. The only way to avoid this was, as Dr. Desch stated, to go further back in the chain of production.

Regarding the hot-milling process alluded to by Dr. Whiteley, one of the authors saw this in operation some years ago, but was not aware whether it was still in use. It was obviously an inferior method to gas descaling.

THE DETERMINATION OF NITROGEN IN FERRO-ALLOYS AND OTHER MATERIALS BY DIRECT NESSLERISATION WITHOUT DISTILLATION.*

By W. C. NEWELL, Ph.D., F.R.I.C., D.I.C., A.R.C.S. (BROWN-FIRTH RESEARCH LABORATORIES, SHEFFIELD).

Paper No. 29/1945 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Sub-Committee on Gaseous and Non-Metallic Inclusions).

SYNOPSIS.

The direct method, without distillation, for the colorimetric determination of nitrogen is further applied to the analysis of ferro-alloys by the addition of stabilising colloids to the Nessler-ammonia coloration. Its application to metallurgical analysis is shown to be extensive, resulting in a far simpler and speedier method for the determination of nitrogen in steel and other alloys.

Introduction.

EVER since J. Nessler⁽¹⁾ in 1856 published an account of the reactions between ammonia and certain complex iodides of mercury, an alkaline solution containing iodides of mercury and an alkali metal has been widely used for the quantitative colorimetric determination of small quantities of ammonia. This "Nessler" reagent has proved itself of great value, particularly in biological and water analysis, and many are the ways in which different investigators have advocated that the reagent should be made up and used. The essential conditions for a satisfactory reagent appear to be that it should be moderately alkaline and should contain potassium and mercuric iodides in proportions as near to the ratio $2\text{KI} : \text{HgI}_2$ as possible. Ammonia reacts with the reagent to form a brown substance, the formula of which, though still somewhat uncertain, is commonly considered to be $\text{NH}_2\text{Hg}_2\text{OI}$. The value of the reagent arises from the fact that, although its reaction product with ammonia is insoluble in water, at low concentrations it is held in colloidal suspension, and thus its dispersive effect upon light is enhanced.

In the usual way in which small quantities of nitrogen are estimated with the reagent, the ammonia is distilled off in the presence of excess caustic soda from an acid digestion of the substance. An appropriate amount of the Nessler reagent is then added to the distillate, which consists of pure water containing the nitrogen dissolved in the form of ammonia. Even in such a pure solution the brown ammonia coloration is not very stable, and most of the attempts to improve the Nessler reagent have only slightly extended the range of stability of the ammonia coloration, usually by reducing the incidental salt concentration. Thus, the reagent has been made up from elemental mercury and iodine,⁽²⁾ as well as by using mercuric oxide or iodide⁽³⁾ in place of the more usual mercuric chloride, which leaves its equivalent of alkali-metal chloride in solution. The suggestions so far

* Received October 25, 1944. This paper is published by authority of the Committee on the Heterogeneity of Steel Ingots. The views expressed in it are the author's, and are not necessarily endorsed by the Committee as a body.

made as to the preparation and use of the reagent are consistent with the idea that the ammonia coloration is due to an electrostatically charged suspensoid, the stability of which is decreased by the presence of ionised salts.

The distillation of strongly alkaline solutions presents laboratory problems which have led some investigators to seek to avoid the operation. Most of these have been concerned with biological problems and unfortunately their conclusions do not appear to have been exploited by metallurgical analysts. Folin and Denis⁽⁴⁾ found that if part of the sulphuric acid used for the preliminary digestion of the substance being analysed was replaced by phosphoric acid, the sodium phosphate formed on making the solution alkaline did not render the ammonia coloration as unstable as did its equivalent of sodium sulphate. They also found, however, that the phosphoric acid had considerable action upon the glass of the digestion vessels used. In 1928 H. M. Chiles⁽⁵⁾ found that a protective colloid such as gum arabic could be used to stabilise the ammonia coloration, even in the presence of considerable salt concentrations, and he recommended direct nesslerisation of Kjeldahl digestions in the presence of gum-arabic solution. L. F. Wicks,⁽³⁾ in 1941, also made reference to the fact that the suspensoid was stabilised by the addition of gums. F. D. and C. T. Snell⁽⁶⁾ also refer to the direct nesslerisation of sewage and to the work of Chiles⁽⁵⁾ with protective colloids. More recently (1942) Gotta and Seehof⁽⁷⁾ applied direct nesslerisation to the determination of nitrogen in ferrous alloys, but, since they attempted only to increase the stability of the suspensoid by keeping the concentrations of alkali-metal and chlorine ions low, the stabilisation is very slight and the application of their scheme very restricted.

The author has experimented with the common colloid stabilisers and has found that gum arabic (*alias* acacia), gum tragacanth, gum agar-agar and starch were all effective in varying degrees. Sodium stearate (soap) was not effective, whilst sodium caseinate and gelatine both appeared to react with the reagent, so that no ammonia coloration was produced at all. Most of these substances contain an appreciable amount of ammonia, but gum tragacanth does not, so that much of the earlier work was done using 20 ml. of a 0.25% solution of gum tragacanth per test. Gum tragacanth, however, forms viscous and somewhat cloudy solutions, even at low concentrations; gum arabic has the advantages that it is the most effective stabiliser and is very soluble, forming solutions of relatively low viscosity. The high natural-ammonia concentration of such solutions is readily eliminated by passing the solution through a column of base-exchanging zeolite.⁽⁸⁾ Synthetic permutit suitable for this purpose is now available on the market. The 5% ammonia-free gum solution is then further purified by filtration after the addition of 10% of its volume of Nessler reagent; the latter appears to react with an impurity in the gum with the production of a small quantity of dark precipitate. In the presence of a suitable amount of gum solution the author has found that the ammonia coloration can be developed regardless of other salt concentrations, and not only can very intense clear colorations be obtained, but dilutions can be made on solutions of too great an intensity without precipitating the ammonia complex. The advantages of this are obvious when unknown ammonia concentrations are being dealt with, as a suitable colorimetric matching may be made by dilution after the ammonia coloration has been developed. The common alkali-soluble metals, aluminium, titanium and tungsten, have been shown to have no action upon the colour, whilst chromium, when present as chromate, interferes by reason of its yellow colour. By the procedure here adopted, however, chromium is not present in this oxidised state.

Analytical Procedure for Steels and Alloys.

A quantity of 1 g. of the steel or alloy is dissolved in 5 ml. of sulphuric acid and 20 ml. of water, after which a few drops of 30% hydrogen peroxide are added to clear the solution of carbides. The solution is then concentrated to fuming for half-an-hour, 2 g. of potassium sulphate being added beforehand if it is known that the steel contains titanium.⁽⁸⁾ The solution is then cooled, diluted and transferred to a graduated 250-ml. flask; 40 ml. of 20% caustic-soda solution are then added, this being sufficient to make the solution appreciably alkaline after the precipitation of most of the metals as hydroxides. The solution is then made up to 250 ml. with distilled water and allowed to settle. Some of the solution is then decanted through a filter which has previously been well washed with dilute caustic soda to remove ammonia, and a measured 100 ml. are transferred into a Nessler cylinder; 5 ml. of 5% gum arabic are added and mixed, followed by 2 ml. of standard Nessler reagent. The solution is then mixed and the colour intensity compared in the usual way with the standard ammonium chloride solution added to 100 ml. taken from a similar blank test, in which the same amounts of gum and salts are present. It is inconvenient to filter off the whole of the solution, owing to the bulk of the hydroxide precipitate, and filtration is avoided altogether if the solution can be left long enough so that sufficient clear decantable solution is obtainable. It is found that two colorimetric comparisons may be made for each test if desired. In accordance with the recommendations of Gotta and Seehof,⁽⁷⁾ insufficient hydrogen peroxide is added to oxidise the whole of the iron to the ferric state, and the black hydroxide formed on addition of the alkali settles out readily. If there is a detectable amount of ammonia in the hydrogen peroxide this can be eliminated by distillation in the presence of sulphuric acid, or, alternatively, 0.1 g. of sodium peroxide may be used for the oxidation.

The possible absorption of ammonia by the hydroxide precipitate was studied by adding a known amount of ammonium chloride solution to an acid solution of pure iron of known low nitrogen content. Within the limits of experimental error the recovery of the ammonia from the ammonium chloride, after the separation of the hydroxide precipitate, was complete. Thus, for example, to a sample of pure iron found to contain 0.0016% of nitrogen the equivalent of 0.008% of nitrogen was added as ammonium chloride, and the test gave an apparent nitrogen content of 0.0094%. It was once accidentally observed, however, that, when a portion of the solution had been filtered and the hydroxide precipitate had been allowed to dry in the filter, a large portion of the ammonia contained in a further quantity of solution was absorbed on passing through the somewhat dry hydroxide on the filter. Clearly, therefore, such conditions must be avoided.

The possibility of there being nitrides in steel, which are only hydrolysed to ammonia by the boiling caustic soda in the normal distillation method, has been suggested by Jordan and Swindells.⁽⁹⁾ So far, the author has not encountered any steels which confirm this suggestion, though the possibility is appreciated, and the results obtained have been carefully compared with those obtained by the vacuum-fusion method or by the conventional chemical distillation method. In Table I. are given some results obtained by the different methods, showing that the agreement between the figures is good.

It was found to be well worth while to keep the ammonia blank down to an absolute minimum by the use of redistilled sulphuric acid, well-boiled caustic soda, distilled water similarly boiled with a little caustic soda and gum solution made ammonia-free by passage through permutit.

TABLE I.—*Nitrogen Contents of Ferro-Alloys by Three Different Methods.*

Material.	Composition.	Nitrogen. %.		
		Vacuum-Fusion Method.	Chemical Distillation Method.	Chemical Gum-Stabilised Method.
Alloy HE9138 . . .	} Cr 18%, Ni 8%, Ti 0.5%	0.013	...	0.013
Alloy OX9200 . . .		0.012	...	0.014
Alloy OX9505 . . .		0.018	...	0.017
Alloy steel :				
No. 3	Al 0.15%	0.012	0.0135	0.0125
No. 4	Cr 3%, Mo 0.6%	0.010	0.0095	0.012
No. 6	Cr 13%	0.019	0.019	0.019
No. 13	Mn 13%, C 1%	...	0.0125	0.013
Alloy 9950	Cr 30%	...	0.077	0.075
Ferro-chrome No. 1 . . .	Cr 70%	...	0.57	0.59
Ferro-titanium E . . .	Ti 40%	...	0.036	0.033

With these precautions the blank becomes negligible, and, owing to the speed with which the determinations can be made, the significance of ammonia absorption from the laboratory atmosphere becomes of less consequence.

During the past few months a single operator has performed hundreds of determinations of the nitrogen content of steel and other alloy samples by this simple no-distillation method using gum. This has represented an enormous saving in time, labour, apparatus and laboratory space as compared with the usual distillation method. A further saving in time and an increase in accuracy are possible by eliminating the visual matching of the colour intensities by the use of a photo-electric absorptiometer.

Analytical Procedure for Organic Materials, &c.

A quantity of 0.1 g. of the material is digested in a Kjeldahl flask with 3 ml. of sulphuric acid for an hour or so (depending upon the stability of the compound) until a clear very pale coloured solution is obtained. The solution is then cooled, diluted and transferred to a 100-ml. graduated flask, in which it is neutralised and made slightly alkaline with caustic-soda solution (25 ml. of 20% solution). The solution is then made up to 100 ml. with distilled water and 25 ml. are removed to a Nessler tube; 5 ml. of a 5% solution of gum arabic are then added and mixed, followed by 2 ml. of the standard Nessler reagent; the whole solution is made up to 100 ml. with distilled water. Some colour usually develops immediately, but it is desirable to leave the solution for at least 5 min. so that the maximum intensity may be developed, after which comparison is made as before with the gum solution, the Nessler reagent, 25 ml. of solution taken from a similar blank test and a solution of ammonium chloride, standardised so that 1 ml. is equivalent to 0.00001 g. of nitrogen. If the colour intensity of the test is too high, then either a fraction of it is taken and suitably diluted, or else a smaller volume of the solution of the substance is used.

Acknowledgments.

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REFERENCES.

- (1) NESSLER : "On the properties of mercuric iodide and the compounds of mercury, particularly with respect to ammonia, and on a new ammonia reaction." Inaugural Dissertation, University of Freiburg, 1856.
- (2) KOCH and McMEEKIN : *Journal of the American Chemical Society*, 1924, vol. 46, p. 2066.
- (3) WICKS : *Journal of Laboratory and Clinical Medicine*, 1941, vol. 27, p. 118.
- (4) FOLIN and DENIS : *Journal of Biological Chemistry*, 1916, vol. 26, p. 473.
- (5) CHILES : *Journal of the American Chemical Society*, 1928, vol. 50, p. 217.
- (6) SNELL and SNELL : "Colorimetric Methods of Analysis," New York, 1943 : D. Van Nostrand Co.
- (7) GOTTA and SEEHOF : *Zeitschrift für analytische Chemie*, 1942, vol. 124, p. 216.
- (8) SWINDEN : Fourth Report of the Oxygen Sub-Committee, Section II., Part C, *Journal of The Iron and Steel Institute*, 1943, No. II., p. 302 F.
- (9) JORDAN and SWINDELLS : *United States Bureau of Standards*, 1922, *Scientific Paper* No. 457.

DISCUSSION.

Mr. G. MURFITT (Messrs. Wm. Jessop & Sons Ltd., Sheffield) : I congratulate Dr. Newell on his presentation of this paper in which he has developed a procedure for the determination of nitrogen without the necessity for distillation. In the introduction the theory of the Nessler Reagent is discussed and it is suggested that the method of making the reagent is critical and affects the stability of the brown ammonia coloration. I should be grateful if Dr. Newell would give us details of which particular Nessler reagent he has used.

CORRESPONDENCE.

Dr. J. E. HURST (Messrs. Bradley and Foster, Ltd., Darlaston) wrote : In view of the fact that the chemical method described by Dr. Newell provides an easy alternative to the vacuum-fusion method and a method for the correct determination of nitrogen, we have tried it out in my laboratory. Repeating the method exactly as described by Dr. Newell, using visual colour comparison, we have found it to give good results, and the chemical operations proved to be fairly easy. The estimations were carried out on two steels, and a cast iron, having nitrogen contents previously determined by the vacuum-fusion method. The results, shown below, agree well with the main values of the vacuum-fusion estimations, and the duplication of the results was, in general, better than the chemical method :

Sample.	Newell's Method. Nitrogen, %.	Vacuum-Fusion Method. Nitrogen, %.
Mild steel . . .	0.0027 0.0029	0.0025 0.0035
Alloy steel . . .	0.0062 0.0064	0.0065 0.0070
Cast iron . . .	0.0047 0.0050	0.0048 0.0050

Mr. A. E. BEET and Mr. R. BELCHER (Department of Fuel Technology, Sheffield University) wrote : Dr. Newell's paper appears to be a useful contribution to metallurgical analysis in that the determination of nitrogen has been simplified and shortened. It is, however, doubtful whether

the method would be of much value in the analysis of organic compounds. In the case of steel analysis, where the "combined" nitrogen percentage is very low, a high relative error can be tolerated so long as the absolute error is of a reasonable order. We consider that in the case of organic compounds, where the nitrogen content may be considerable, the relative error would be too large even for routine operation. Had some analyses of organic compounds been included it would have allowed a better assessment of this point to be made.

However this may be, distillation methods are so rapid that it is doubtful whether any real advantage in speed would result from abandoning them. There would probably be so little in it that most chemists would hesitate to change over to a method that would probably be less dependable.

Our main purpose in contributing to this discussion is to indicate that Dr. Newell has described a digestion method for organic compounds which would be of extremely limited application. He has erred in assuming that Kjeldahl digestions are necessarily complete when the acid solution has become clear or colourless.

It has been known for many years that nearly all Kjeldahlized organic bodies need a more or less prolonged heating (the "after-boil") after the acid solution has become free from char. The use of accelerators such as mercury compounds, copper sulphate, selenium compounds, &c., usually allied with boiling-point elevators, such as potassium sulphate, greatly reduces the period of digestion necessary but can never avoid the necessity of the after-boil.

As regards the ease of conversion of nitrogen in organic compounds into ammonia, three distinct groups of compounds can be recognized :

(1) Amino bodies or substances readily converted into them, such as glycine, cereals, &c., require little or no after-boil.

(2) Pyridine and quinoline derivatives and alkaloids, which char little or not at all with concentrated sulphuric acid, need a prolonged after-boil the duration of which is always to some extent uncertain. Substances such as nicotinic, quinolinic, picolinic and pyridine-sulphonic acids do not char when heated with strong sulphuric acid.

(3) Compounds containing nitrogen linked with oxygen cannot be Kjeldahlized without modification. However, a preliminary treatment with hydriodic acid and red phosphorus converts such bodies into amino bodies which then fall into group 1, and so can easily be Kjeldahlized.

Bituminous coals appear to contain their nitrogen as amino bodies and as pyridine or similar ring compounds, the whole of the former and probably a portion of the latter compounds present being converted into ammonia up to the char-free stage. The substances that will be converted during the after-boil have been isolated by one of us (A. E. B. in 1933) from coal. As illustrative of the error introduced by omitting the after-boil in the Kjeldahlization of coal the following figures (the averages of several hundred tests) (A. E. B.) may be given :

Bituminous Coal.

Treatment.	Nitrogen, %.	Nitrogen Recovered, %.
Heated with sulphuric acid only until char-free	1.40	85.4
Heated with sulphuric acid plus K_2SO_4 until char-free	1.51	92.1
Heated with sulphuric acid plus K_2SO_4 and HgO until char-free	1.54	93.9
Heated with sulphuric acid plus K_2SO_4 and HgO until char-free and then boiled for 2 hr.	1.64	100.0
Heated with sulphuric acid plus K_2SO_4 and HgO until char-free and then boiled for 5 hr.	1.64	100.0

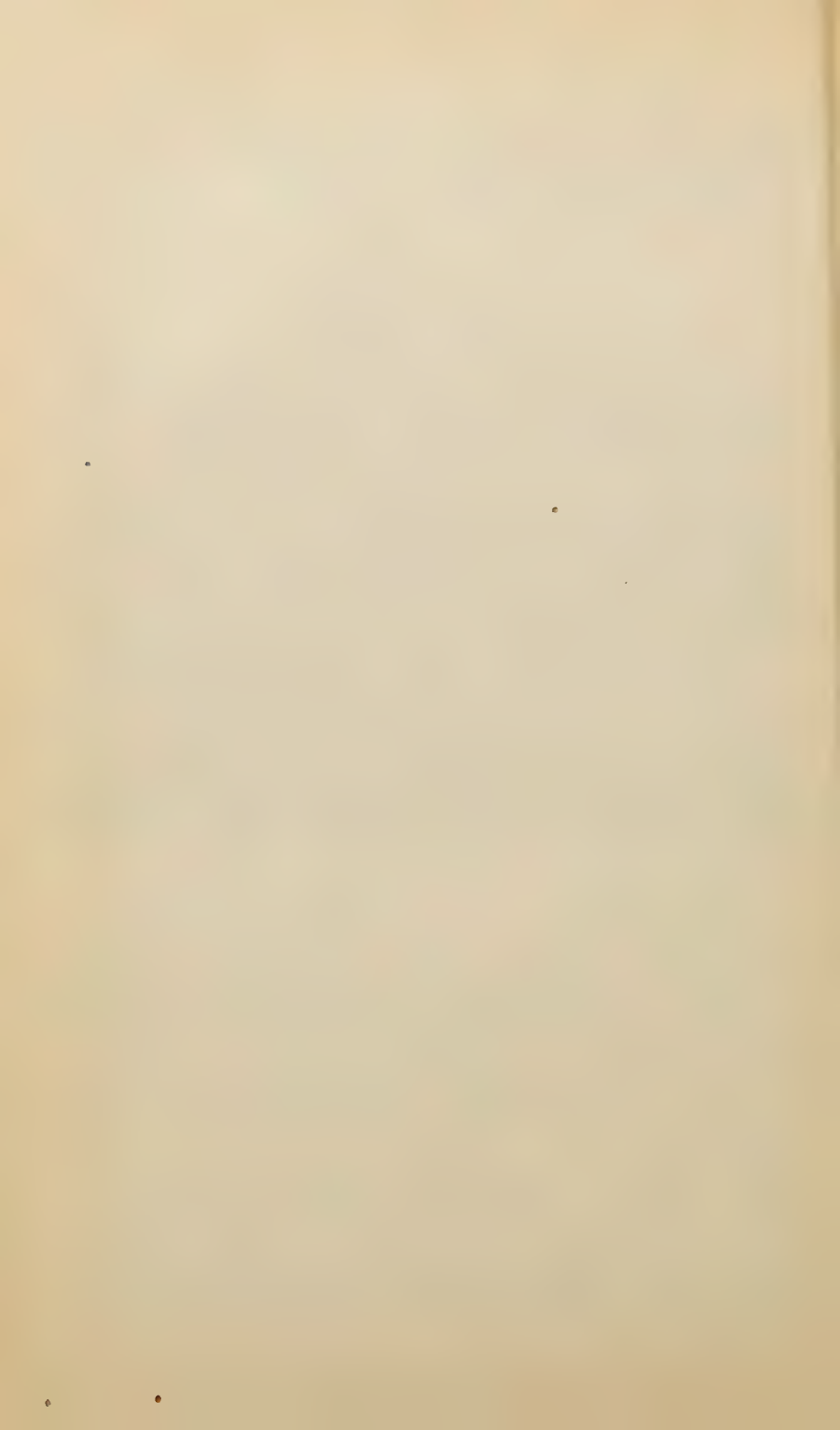
We realize, of course, that the main purpose of this paper was to provide a simple and rapid method for the analysis of steels and allied substances. This object appears to have been achieved. We feel, however, that it is necessary to correct the impression given that organic compounds can be dealt with in as simple a manner as that described in Dr. Newell's paper.

AUTHOR'S REPLY.

Dr. NEWELL wrote in reply : In answer to Mr. Murfitt's query regarding the relative merits of the various methods of making up Nessler's reagent, I would say that there is no observable difference in the colour intensity or in the clarity of the solutions produced therefrom, provided that sufficient stabilising gum is present. To minimise the quantity of gum necessary it is desirable to reduce the salt concentration of the solution to a minimum, and on this account a Nessler reagent with a minimum incidental salt concentration is to be preferred. On this score the Nessler reagent made up from elemental mercury and iodine is most favourable, but it has the disadvantage that the preparation of this form of the reagent is a lengthy operation. In actual practice the amount of incidental salts added by Nessler reagent of any composition is so small as to make the distinction between the different compositions to be of little consequence. The important conclusion from our work is that by the simple addition of only moderate amounts of gum, salt concentrations can be ignored.

I am grateful to Dr. Hurst for the information that his laboratory has confirmed the usefulness of the new method, and for the analytical results which illustrate the degree of reproducibility of the figures and their agreement with those obtained by the vacuum fusion method.

I agree entirely with the comments of Mr. Beet and Mr. Belcher regarding the use of the method for organic analysis, but, as they realise, the main purpose of the paper was to provide a simple method for the analysis of steels and allied substances.



DOLOMITE LININGS FOR BASIC ELECTRIC ARC FURNACES.*

By E. C. BRAMPTON, H. PARNHAM, AND J. WHITE, PH.D., D.SC. (GENERAL REFRACTORIES, LTD., SHEFFIELD).

(Figs. 4 to 7 = Plates XXXVI. to XXXIX.)

SYNOPSIS.

The severity of the conditions to which refractory linings are subjected in the basic electric furnace is indicated by the fact that the life obtained is generally only one-third to one-quarter of that obtained in comparable positions in the open-hearth furnace. The special conditions to which the refractory is subjected in the arc furnace are discussed, and the need for collaboration between the refractory maker and the furnace user is stressed.

A brief account is given of the development of basic linings for electric furnaces, with particular reference to the development of the 100% dolomite brick, which has been widely adopted in this country in recent years. The advantages of this brick are discussed. An account is given of a trial in a 4-ton furnace of a 100% dolomite brick roof which gave a life of 57 heats under severe conditions. Clear indications were obtained during the trial that such a roof would make the attainment of higher furnace temperatures possible, and would materially increase side-wall life.

A review of refractory performance data supplied by the users of furnaces in which 100% dolomite brick linings are employed is given, and the general method of installing such linings is indicated and illustrated by diagrams. The methods of manufacturing dolomite bricks, both of the stabilized and of the 100% type are described in general terms.

An account is given of a series of investigations relating to the behaviour of 100% dolomite bricks in arc furnaces. A notable feature is that, as a result of drainage and of migration of lime in the form of fusible compounds away from the hot face, the working face of the brick tends to acquire increased resistance to fluxing while in service. X-ray analysis shows that in used bricks the zone in the immediate vicinity of the working face consists mainly of spinel and periclase, with other divalent oxides in solid solution. Analytical and X-ray data are also given for the principal zones formed behind the hot face in portions of brick removed from a furnace at the end of the oxidizing and reducing periods respectively, and the effects of the fluctuating atmospheric conditions are discussed. It is shown that the phases identified in the various zones are consistent with known equilibrium phase data for the system $\text{CaO-MgO-Fe}_2\text{O}_3(\text{FeO})\text{-Al}_2\text{O}_3\text{-SiO}_2$. The occurrence of "flaking" or splitting-off of the brick at a position between 1 and 2 in. behind the hot face, which sometimes occurs with dolomite bricks (as well as with other basic refractories) as a consequence of flux penetration, is also described and possible mechanisms discussed. Stress is laid on the importance of maintaining adequate support at the hot face and of avoiding excessive undercutting to ensure optimum performance.

The application of the method of sulphur printing on bromide paper to demonstrate the presence of sulphur as sulphide in used bricks is also described, and it is shown that the concentration of such sulphide is low in the vicinity of the hot face and reaches a maximum in certain light-coloured zones some distance into the brick. This is probably responsible for a certain "softening" observed in used bricks in a zone immediately beyond the limit of flux penetration.

Analyses are given of gas samples drawn from furnaces during the refining (reducing) period. These indicate that very highly reducing atmospheres may arise at certain stages of the refining process, and that reduction of iron oxide at 1600° C. to a stage intermediate between FeO and Fe_3O_4 , but approaching the former, is to be expected.

* Received September 17, 1945.

Samples of refining-period fume have also been analysed, and the "fixed" constituents were found to be mainly MgO , CaO , iron oxide, and silica. There was also an appreciable content of carbon, apparently combined, and of sulphur as sulphide. The mechanism of fume formation is discussed, and its importance as a source of flux deposition on the refractories is indicated. Its composition is such that basic refractories will be much less affected by it than acid refractories.

FROM the point of view of the user of basic electric furnaces the refractory lining is perhaps the most important part of the structure. In particular, it is the refractories which in practice impose a limit to the temperatures attainable, and, in addition, because of the comparatively frequent need of replacement, it is the refractories which to a large extent determine the ultimate cost of the process.

In the past the choice of refractories for basic electric furnaces has been largely influenced by open-hearth practice. This was perhaps natural and inevitable, particularly since the choice of refractories serviceable at steel-making temperatures and under steel-making conditions has never been a large one. There is little doubt, however, that from the point of view of refractories the electric furnace represents a specialized problem and must be studied as such. It is only by adopting this approach, and by carrying out carefully planned and supervised trials involving close co-operation between the refractory manufacturer and the user, that the best practice can be arrived at, or that new refractories suitable for the basic electric process can be evolved. The development of the semi-stable 100% dolomite brick for electric furnaces by a firm of refractory manufacturers in collaboration with a firm of steelmakers provides an excellent example of such co-operation.

The dictum that only by careful control of furnace operating conditions can the best performance be obtained from the refractory lining, while true of any furnace, is particularly true of the electric arc furnace, in which the heat source is very intense and is limited only by the electrical capacity of the furnace. The use of arcs longer and more intense than the circumstances warrant, or over-long exposure of the refractories to the unshielded heat of the higher-voltage arcs, will inevitably lead to a short lining life.

THE EFFECT ON REFRACTORY LIFE OF CONDITIONS IN BASIC ELECTRIC FURNACES.

The conditions obtaining in the basic electric furnace, insofar as they affect the life of the refractory, are noticeably different from, and on the whole decidedly more severe than, conditions in the open-hearth furnace. In particular the following six factors are such as to have a decisive effect on refractory performance.

(1) *The Intense Nature of the Source of Heat and the relatively close proximity of the arcs to the side-wall and roof refractories.*—The temperature of the electric arc is estimated to be between 3500° and 4000° C., so that radiation from the unshielded arcs to the surface of the refractories is very intense. This is particularly so with the higher voltages and longer arcs now commonly used. Apart from the fact that it may cause the surface of the refractory to rise above its melting point unless proper control is effected, the arc also causes an exceedingly rapid temperature rise to take place, accompanied by a steep temperature gradient through the refractory when the furnace is switched on. This can easily cause spalling, which with some refractories, *e.g.*, magnesite in the side walls, may be sufficiently severe to become a major factor in determining their life. Silica roofs can also be spalled excessively unless care is exercised.

(2) *The Intermittent Nature of the Heating and the relatively frequent alternations of heating and cooling periods.*—Owing to the relatively small size of most furnaces, cooling as well as heating tends to be rapid. The effect is accentuated if a detachable roof is fitted for basket charging. This device curtails the time of cooling by cutting down the charging time, but, on the other hand, the sudden introduction of all or most of the charge in one operation causes a rapid chilling of the surface of the refractory. It is, in fact, quite usual to find the surface temperature of the refractory dropping to a black heat before melting is started again. Hence, during a very large part of its working life, the refractory is being subjected to rapid temperature changes and the steep temperature gradients resulting from these. Thus thermal stresses are repeatedly set up within the brickwork, and their tendency to cause spalling is likely to be accentuated when flux penetration and zoning have occurred, resulting in differences in the thermal expansion, diffusivity, strength, and elasticity of the various zones.

(3) *The Frequent Alternations between Oxidizing and Reducing Conditions.*—The bulk of the iron oxide pick-up by the refractories occurs during the oxidizing period, when the iron oxide additions are made and the slag is rich in iron oxide. The main causes of such pick-up are dust produced during the charging and feeding of the ore, splashing of the slag during feeding and during the boil, and volatilization of iron oxide from the slag and the metal bath. At the same time oxidation of iron oxide deposited on the refractory or within its pores will tend to occur. During the reducing period iron oxide pick-up will possibly be small, as no iron oxide additions are made, and the bath is covered by a slag which soon becomes almost entirely free from iron oxide. During this period, however, reduction of iron oxide which has already been deposited on the brickwork or within the pores will occur, accompanied, in general, by an increase in its solvent power for the refractory, which leads to accelerated attack on the refractory and to increased flow and drainage at the working face. At the same time certain volume changes affecting the still-solid part of the refractory may occur, and may aggravate tendencies to spalling and disintegration in certain cases.

(4) *The Large Proportion of Fluorspar Used Relative to the Weight of Slag.*—In general the weight of fluorspar used per unit weight of slag in making the reducing slag is high, because of the absence of other fluxes in the slag and the necessity for reaching a high lime concentration in order to achieve efficient desulphurization. Thus considerable evolution of fluorine from the slag is to be expected, and this will materially accelerate the wear of siliceous refractories. In addition, a certain amount of fluorspar is likely to be carried to the refractories, *e.g.*, as powder during charging, as occurs with lime, or as a constituent of slag droplets during the boil. Since it is a powerful flux this fluorspar will intensify the attack on refractories of all kinds.

(5) *Volatilization of Fluxes.*—In the vicinity of the arcs rapid volatilization of the more volatile fluxes will occur. Chief among these is probably iron oxide, particularly during the oxidizing period. It is known that the transfer of iron oxide in the vapour state plays a big part in the fluxing of roofs, walls, &c., in open-hearth furnaces. In the electric furnace, with its restricted space and high local temperatures in the vicinity of the arcs, the action of iron oxide is likely to be intensified.

(6) *High Proportion of Alloy Steels Made.*—The products of basic electric furnaces usually include a high proportion of alloy steels, some of them of the "difficult" varieties. These often necessitate the use of bath and slag temperatures higher than normal, and sometimes these temperatures must be held for fairly long periods. This tends to cause excessive melting and fluxing of the roof and walls of the furnace.

It will be noted that all the above factors are such as to intensify the wear on the refractories and to shorten their working life. On the other hand, except for the electrode ports, electric-furnace refractories are not subjected to any considerable extent to direct impingement of flame, or to the cutting action of fast-moving gases, as occurs in open-hearth and other gas-fired furnaces; but, even allowing for this, and even with the best practice and the most careful control of the arcs and of the arrangement of the scrap to shield the refractories during melting down, conditions are undoubtedly severe. This is borne out by the fact that the rate of wear of roof and wall refractories in basic electric furnaces is generally at least three to four times as rapid as in similar positions in the open-hearth furnaces.

THE LINING OF BASIC ELECTRIC FURNACES.

The complete lining of a basic electric furnace is generally carried out as follows. On the furnace bottom next to the shell is laid a 3- or 4½-in. course of firebrick. The chief rôle of this layer is to ensure that there is sufficient thickness of refractory between the surface of the hearth and the shell to keep the latter cool, without incurring the full cost of an extra course of basic bricks. This layer is, therefore, in a sense an insulating one, and the low thermal conductivity of firebricks relative to basic bricks is thus an advantage. Some users actually employ insulating material in this position, but the practice is not general and the question of its desirability or otherwise has apparently not been settled. Some hold the view that it leads to higher fettling costs and to increased likelihood of bottom trouble.

On top of this course are laid two, or sometimes three, courses of basic brick. Round the circumference adjacent to the shell of the furnace, six or more additional courses are built on top of these, starting with a thickness of three to four 9-in. brick lengths in the bottom course, corbelled down to two 9-in. brick lengths in the upper courses, with suitable modifications to allow for the shaping of the hearth towards the tap-hole spout. The corbelling thus follows roughly the final shape of the hearth and allows the rammed material to be keyed firmly to the brickwork. These corbelled courses also provide a firm foundation on which the side walls proper are built. These latter extend to the top of the shell.

Formerly, magnesite bricks were commonly used for the bottom and corbelled courses and were carried up the sides to about two courses above the slag line. Above this the walls, including the jambs and arches of the door and tap-hole openings, were built of silica, except for a neutral course of chrome brick interposed between the magnesite and the silica. This practice has largely fallen out of favour (though it is still used to a small extent), since, under the strongly basic conditions prevailing in the furnace, rapid corrosion of the silica is likely to occur. This leads to excessive drainage of siliceous liquids down the walls, resulting in cutting of the basic banks, and it also has the undesirable effect of introducing unwanted silica into the slag. This behaviour is aggravated with the high-voltage arcs now commonly used.

The advantages of using basic material for the side walls were early realized, but the shortcomings of the basic refractories then available probably delayed the general adoption of this practice. In the early nineteen-thirties, however, marked advances were made in the technique of basic refractory manufacture, which led to improvements in magnesite bricks and to the development of the modern chrome-magnesite brick. The adoption of magnesite and chrome-magnesite bricks for side-wall construction followed. Chrome-magnesite bricks were also used by some to replace all or part of the magnesite bricks underlying the hearth, this practice being claimed to give greater protection against break-outs.

As alternatives to bricks, metalkase magnesite and rammed dolomite are also used for the construction of basic side walls. The former is at present enjoying a considerable vogue in the United States, where very long lives—in some cases up to 300 heats—are claimed for it. Operational conditions there, however, appear to be somewhat different from those in this country. For example, the furnaces are generally larger and the walls correspondingly farther from the arcs, and trials of this material in British furnaces do not appear to have been overwhelmingly successful. The use of rammed dolomite linings, on the other hand, has achieved greatest popularity on the Continent, and some linings of this type have been and are being used in this country. With proper control of the preparation and installation of the material * lives of the order of 100 heats are obtainable. If, however, this control is relaxed, lining life soon falls away. It is largely because of this, and of the time involved in preparing and installing such linings, that several operators who at one time used rammed linings have now gone over to dolomite brick linings.

About 1936 an important development occurred in this country in the successful production on a commercial scale of a stabilized dolomite clinker. Bricks made from this material were soon being produced by a number of refractory manufacturers, and were found suitable for use under the hearths of basic electric furnaces in place of magnesite. Their use for this and similar purposes during the war years has resulted in a large saving of the latter material. They are not, however, generally recommended for use in more exposed positions in the electric furnace, as their slag resistance at high temperatures is rather low.

For some years before the war, two British firms had worked in close co-operation with a view to producing a dolomite brick suitable for electric-furnace use. Success was achieved and for a number of years practically the whole of one of the firms' requirements for basic electric-furnace side walls were satisfied by this material, which gave decidedly longer lives than anything used previously. Ultimately they adopted S.S.D. (semi-stable dolomite) bricks to the complete exclusion of magnesite, except for the skewbacks of silica arches (when these were used) and a single course of stabilized dolomite bricks on the furnace bottom next to the shell (or next to the firebrick course when one was used).

In 1940 the shortage of imported raw materials, coupled with the large increase in the number of electric furnaces in use (many were installed by the Ministry of Supply to meet the heavy demands for alloy steels), led the brickmaking firm concerned to undertake extensive research and development work and the installation of additional plant to make S.S.D. bricks more widely available. Since then the use of these bricks in basic electric-furnace side walls, arches, jambs, and bottoms has been widely adopted throughout the country, and this has resulted, as in the case of stable dolomite bricks, in a very substantial saving in magnesite and chromite during the war. It must be emphasized, however, that they are not to be regarded merely as a war-time substitute for the others, as service data collected from various users show that for this application they are generally superior to them. In this connection it can be revealed that some time ago a furnace lined with S.S.D. bricks was continuously operated on a process which called for a bath temperature of 1725° C. as measured by the Schofield-type quick-immersion pyrometer. Actually 1750° C. was reached on many occasions. Nevertheless, this work had surprisingly little effect on the S.S.D. lining, though it proved disastrous to a succession of silica roofs.

As indicated above, the adoption of basic side walls was a big step forward in the technique of lining basic electric furnaces. Now, of the

* This involves close control over gradings of the selection and mixing-in of the tar, and of the ramming operation.

refractories exposed inside the furnace, only those comprising the roof and, in some cases, parts of the door and tap-hole openings are acid, being generally of silica or, less commonly, aluminous (42-44% of Al_2O_3) fire-bricks, and while this has greatly minimized the troubles due to the dripping and running of siliceous liquids on the basic refractories, corrosion of the side walls and banks does still occur from this cause, even when the practice of placing corbelled courses of chrome-magnesite brick on top of the basic side walls is adopted. The next logical development would therefore be the use of a basic roof, provided that basic roof blocks of suitable properties could be produced on a commercial scale. This would materially increase side-wall life, eliminate cutting of the banks, and make a more accurate control of slag composition possible. Trials with this end in view are at present being carried out.

At the time of writing, the first S.S.D. roof has just ended its life. It was on a 4-ton furnace and was 9 in. thick, its design being a somewhat modified form of the British Refractories Research Association standard design; $9 \times 4\frac{1}{2} \times 2\frac{1}{2}$ -in. tapered dome bricks were used for the annulus and $9 \times 4\frac{1}{2} \times 3$ -in. standard shapes in the centre. The electrode port assemblies were constructed from $12 \times 4\frac{1}{2} \times 3$ -in. side-arch blocks. In addition to the roof, the side walls, the charging and tapping door arches and jambs, and the basic course under the hearth were all constructed of S.S.D. bricks. During the trial the furnace was operating only one 8-hr. shift per day, coke being charged on to the hearth during the idle periods to conserve the temperature. In spite of this, there would be considerable temperature variation throughout the refractories during each 24-hr. period. Another point was that several times during its life the roof was subjected to temperatures appreciably greater than normal. This arose from the fact that, owing to its greater refractoriness, the roof did not drip, as does a silica roof, when the temperature becomes excessive, so that the usual indication of high temperature looked for by the melters was absent.

The roof finally did 57 complete heats. From observations during its life and examination afterwards, it was evident that wear had been mainly due, not to fluxing at the working face, but to a periodical flaking or splitting-off of the working face, generally in pieces 1-2 in. thick. This was first noticed after about a week in service and soon resulted in the underside of the roof assuming a "stepped" appearance. On examination of the roof afterwards, examples of such "flakes" in the course of development were found in the form of what looked like "hot tears," generally 1-2 in. behind the hot face. They appeared to be caused by loss of hot strength at working temperatures, consequent upon the penetration of fluxes and zoning.

The life obtained from this roof is regarded as distinctly promising. In particular, in refractoriness and resistance to fluxing at the hot face it was markedly superior to silica, and it was obvious that it could be run at a much higher temperature than silica without melting. The latter is a particularly important point, since at present the temperature in electric furnaces is limited by the melting point of the silica roof. In addition, it was evident that the use of a dolomite roof would materially increase the life of the dolomite side walls, as, when the roof was taken off, the walls were still in very good condition and would have been capable of giving considerably longer service..

REVIEW OF CURRENT SERVICE DATA ON BASIC FURNACE LININGS.

A questionnaire was recently issued to a number of firms using basic electric furnaces. All the firms are at present using S.S.D. bricks for side-

wall construction. The answers to the questionnaire are given in a condensed form in Table I. and can be considered as representative of present-day (war-time) practice, covering the manufacture of a wide variety of carbon and alloy steels for ingots and castings.

One of the most striking features of this collection of data is that the furnaces are invariably charged in excess of their rated capacity. This appears to be a natural tendency at any time, but has, of course, been accentuated during the war years owing to the vital necessity for obtaining the maximum possible production of steel.

One effect of such over-charging is to lift the slag line higher up the banks to a level at which they are thinner. As a result there may be a certain amount of erosion of the brick wall at this point, owing to the banks being too thin to resist completely the penetration of slag and metal. Another practice associated with over-charging which acts to the detriment of the furnace, results from the fact that it may be impossible to introduce the complete charge into the furnace at one operation. It may, therefore, be necessary for the roof to be swung twice, or even three times, during the melting-down stage to accommodate the whole charge.

Still another factor to be taken into consideration when assessing the significance of the performance figures quoted, is the present-day tendency to use the electric furnace as a quick-melting unit. This entails the use of high voltages and heavy currents to produce long arcs, which, as previously mentioned, markedly increase the severity of the conditions to which the refractory is subjected.

When account is taken of the foregoing conditions, it would appear that S.S.D. bricks perform very creditably in side walls, and if any operator is not getting a life of some 70 to 80 heats from side walls composed of these bricks, it is probable that certain conditions exist which require further investigation.

It may be noted that the performance figures in Table I. are quoted in terms of heats, which was the form asked for in the original questionnaire. This appeared to be the best basis of comparison, since it was known that furnaces were being worked intermittently by some operators and continuously, except at week-ends, by others. But, since melting times are given, it is a simple matter to estimate the life on a time basis. Actually, many furnace operators are mainly interested in the number of complete weeks a lining will last, since it is their practice to carry out repairs and re-linings during the week-end. This accounts for the desire expressed by some users for a longer dolomite crown brick for side-wall linings, as it often happens at the end of a week's run that there may be three or four days' life left in the lining, equivalent, perhaps, to some 15 to 20 heats; yet the lining has to be taken out at the week-end to avoid the risk of a midweek shut-down. Certain technical problems have, however, still to be overcome before blocks of the sizes suggested can be made generally available, though 12-in. shapes can now be made in somewhat limited numbers.

Table I. does not provide a direct comparison of the relative performances of dolomite, magnesite, and chrome-magnesite in side walls. To be of any value such comparisons must be based on performance figures obtained under identical operating conditions. It is difficult, however, to obtain data which fulfil these requirements with certainty. Thus it is in general somewhat unsafe to compare the performance of dolomite at the present time with the performance of magnesite or chrome-magnesite several years ago, even when only one furnace is involved in the comparison; it is generally found that, in the interim, modifications of various kinds have been made to the furnace and the process, and that the balance between the various types of steel made in the furnace has altered considerably.

TABLE I.—Operating Data for

Furnace:	A.	B.	C.	D.
Capacity, tons:				
Normal	7	3	6	8
Actual	7/7½	3½	6½/7	10/12
Charging	Hand	Hand	Bucket	Bucket
Rating, kVA.	720	...	2300	3000
Operating Conditions:				
(a) Initial heating-up . . .	Melting charge.	Coke.	Coke.	Melting charge.
(b) Nature of charge . . .	Scrap.	Scrap.	Scrap.	Scrap and turnings.
(c) Steel made	Alloy.	Alloy.	Carbon and alloy.	Carbon and Ni-Cr-Mo.
(d) Duration of heat, hr. . .	4½	4½	4½/5½	5/7
(e) Bath temp., ° C.	1600	1600	1600/1700	1560/1600
(f) Slags	O. and R.	O. and R.	O. and R.	O. and R.
(g) Operation	Con- tinuous.	Con- tinuous.	Inter- mittent.	Inter- mittent.
Lining Details:				
(a) Bottom	6" M. + 1' 2" G.D. : 9" M. + 3" G.D. at slag line.	1" F.B. Splits + 2½" F.B. + 3" D. + 6" G.D.	3" D. + 3" S.S.D. + 7" G.D.	S.S.D. + G.D.
(b) Side walls	9" S.S.D.	13½" S.S.D.	13½" S.S.D.	12" S.S.D.
(c) Door arch	H.F.	S. (1 ring).	S.S.D. (2 rings).	S.S.D.
(d) Door jambs	4½" C.M. inside, 4½" H.F. outside.	S.S.D.	S.S.D.	S.S.D.
(e) Tap-hole	4½" C.M. all round.	S.S.D. (+ 2 rings S. in arch).	S.S.D. (2 rings in arch).	S.S.D.
Lining Life in Heats:				
(a) Bottom	1050	792	...	489
(b) Side walls	105	90	76/106	85
(c) Door arch	21	90	25/30	28
(d) Door jambs	21	25/30	25/30	28
(e) Tap-hole	42	25/30	25/30	28

NOTES ON TABLE I.

(1) Furnaces *A*, *C*, *G*, and *H* have two courses of chrome-magnesite, and furnaces *B*, *D*, *I*, *J*, and *K* have one course, at the top of the wall. *H* has three courses of chrome-magnesite at the base of the wall, while *J* has two, and *K* has two of magnesite.

(2) *B* has chrome-magnesite between the silica of the door arch and the dolomite wall. *I* has chrome-magnesite between the dolomite jambs and the silica slab forming the top of the door.

(3) *Dolomite side walls*.—Flaking is given as a cause of failure in furnaces *A*, *B*, *F*, and *G*. Spalling on shutting down is said to occur in *C*, which is worked intermittently. Channelling due to roof drips occurs in *G* and *K*. In *E* the chief cause of failure is collapse following collapse of the silica arches.

(4) *Door arches*.—Flaking of dolomite door arches occurs in *C*, *D*, *F*, and *G*. Melting is the chief cause of failure in all furnaces having silica arches, except *J*, in which it is mechanical abuse. The latter is given as a contributory cause in several other cases as well.

Basic Electric Arc Furnaces.

<i>E.</i>	<i>F.</i>	<i>G.</i>	<i>H.</i>	<i>I.</i>	<i>J.</i>	<i>K.</i>
7½ 8/9 Hand. 3500	8 10 Bucket. 3000	10 11½ Bucket. 3750	10 10 Bucket. 3500	4 4½ Bucket. 1500	15/18 18 Charger. 4500	10 12/14 Hand. 3500
Charge.	Charge.	Coke.	Charge.	Charge.	Coke.	Coke.
Scrap.	Scrap.	Scrap and turnings.	Alloy scrap.	Scrap.	Scrap.	Scrap.
Stainless.	Carbon and alloy.	General.	A.I.D. spec.	Mn-steel.	General.	Alloy.
5½/6 1575/1625 O. and R. Con- tinuous.	6½ 1620/1650 O. and R. Con- tinuous.	6 1620 O. and R. Con- tinuous.	6 1640 O. and R. Con- tinuous.	2½ 1650 O. and R. Con- tinuous.	8 1625 O. and R. Con- tinuous.	4 1650 O. and R. Con- tinuous.
M. + G.D.	24"/14" (Crespi).	2½" F.B. + 6" D. + 3" S.S.D. + G.D.	1 course I.B. + 1 course F.B. + 2 courses M. + 9" G.D.	Crespi.	3" F.B. + 9" C.M. + 9" G.D.	9" M. + G.D.
13½" S.S.D. S.	13½" S.S.D. S.S.D. (4 rings). S.S.D.	18" S.S.D. S.S.D.	S.S.D. S.	9" S.S.D. S. (slab) S.S.D.	9" S.S.D. S.	9" S.S.D. 18" H.F.
S.	S.S.D.	S.S.D.	C.M.	S.S.D.	S.	9" M. inside, 9" H.F. outside. M.
S.	G.D. (Crespi).	S.S.D.	C.M.	S.S.D.	C.M.	
750/1000 75 40/45 40/45 40/45	... 80/110 30/50 30/50 80/110	... 80 50 50 50	1000 92 46 repair 46 46 "	750 120 60 60 120	340 85 17 17 40	450 70 12 15 70

(5) *Door jambs*.—Flaking is described as the chief cause of failure in *C*, *D*, and *F*. Melting and mechanical abuse are the chief causes in the others.

(6) *Tap-holes*.—Flaking is described as occurring in *D* and *G*. In the others slag attack and metal erosion of the jambs are the chief causes.

KEY.

- O. and R. = Oxidizing and reducing.
 S.S.D. = 100% dolomite bricks.
 D. = Stable dolomite bricks.
 C.M. = Chrome-magnesite bricks.
 M. = Magnesite bricks.
 S. = Silica bricks.
 G.D. = Rammed dolomite.
 F.B. = Firebricks.
 H.F. = 42-44% Al₂O₃ firebricks.
 I.B. = Insulating bricks.

Be that as it may, however, inquiries show that most steelmakers using dolomite brick side walls are of the opinion that longer lives are obtained with these than were formerly got with either magnesite or chrome-magnesite. The following life figures supplied by one such user for continuously-operated furnaces are fairly typical:

Material.	Average Life.	Number of Heats.
Magnesite side walls	3 weeks	65/70
Chrome-magnesite side walls	3 "	65/70
S.S.D. dolomite side walls	4½ "	95/100

This represents an increase of 50% in the average wall life when using S.S.D. bricks.

The same firm stated that the main factor determining the life of magnesite walls was spalling, while with chrome-magnesite it was growth, bursting, and general disruption of the working face. Dolomite, on the other hand, slagged away uniformly and regularly throughout its working life. Some users, however, report a tendency under certain conditions for dolomite bricks to split off an inch or so behind the hot face, this being described as "flaking." This is apparently due to the concentration of fluxes behind the hot face, and, of course, contributes to the total wear on the bricks involved.

Variations in Practice.

The questionnaire revealed differences in detail in the practice adopted by the various users. The chief points can be summarized as follows.

Bottoms.—Rammed dolomite was used exclusively for the actual hearth. The total thickness of the bottoms varied considerably, as shown by the figures quoted. There also seems to be no general agreement on the choice of materials for use under the hearth. Magnesite, chrome-magnesite, 100% dolomite, and stable dolomite are all used. Two of the furnaces had Crespi bottoms.

Side Walls.—No definite relationship appears to exist between wall thickness and furnace capacity. Thus 9-in. walls are used on furnaces ranging from 7 to 15 tons capacity, 12-in. walls on furnaces of from 8 to 12 tons, and 13½-in. walls on furnaces of from 3 to 10 tons. One furnace, *G*, with a nominal capacity of 10 tons had 18-in. walls. The choice of wall thickness seems to be conditioned mainly by the opinions of the operator with regard to the most economical thickness to use and possibly, in some cases, by the desire to keep the capacity as large as possible with a given size of casing.

The manner of building up the various wall thicknesses is as follows:

9-in. wall	Single ring of 9-in. crowns.
12 " "	Ring of 9-in. crowns plus 3-in. backing course.
13½ " "	Ring of 9-in. crowns plus 4½-in. backing course.

The 18-in. wall thickness of furnace *G* is made up of two concentric rings of 9-in. dolomite crowns in a new lining. The thickness is maintained at 18 in. each time a repair is carried out until it is no longer possible to obtain an 18-in. foundation at the slag line. The thickness is then reduced to 14 in. and later to 9 in., depending on the thickness of the foundation. Another firm in this country constructs an 18-in. wall from 9 in. of dolomite with a backing of 4½ in. of magnesite and 4½ in. of firebrick on the outside. The firebrick serves as insulation, and the magnesite as a safety course and enables the dolomite to be used till it is worn right back before replacement. This accounts for a substantial saving in dolomite. At the same time, the backing bricks are almost untouched and can be used again.

Both of these practices have much to commend them, but require a somewhat generous size of casing for a given tapping capacity.

The question of wall thickness is undoubtedly an important one from

the point of view of furnace efficiency and of temperature gradient and its effect on the wear of the refractories, and also from the point of view of the proportion of the dolomite usefully consumed during the working life of the wall, and of the labour costs in re-lining. A study of the factors involved from the point of view of costs would probably be well worth while.

Door Arches and Jambs.—The questionnaire revealed that the principal cause of failure of S.S.D. bricks in these positions is "flaking" or splitting-off of the hot face, while with silica and firebrick it is melting and excessive fluxing. It is also known that some shrinkage may occur with dolomite bricks in these positions, and it is not generally recommended that they should be used in arches with a span greater than 2 ft. 6 in. The rise on arches should be not less than $1\frac{1}{4}$ in./ft. of span. Nevertheless, the performance figures quoted for these bricks compare very favourably on the whole with those given for silica and chrome-magnesite, and are decidedly better than those for magnesite and firebrick. The fact that the door opening is exposed to considerable mechanical damage, particularly when machine- or hand-charging through the door is employed, should, however, be borne in mind, as this practice undoubtedly has a determining influence on the life obtained.

Tap-Hole Opening.—The highest figure quoted, 120 heats, is for a tap-hole constructed of S.S.D. bricks. The furnace in question is a small one of only 85 cwt. capacity. The best figure quoted for a larger furnace is given by rammed dolomite in furnace *F* which gives 80–110 heats. The figure of 50 heats for dolomite bricks as quoted for furnace *G* can probably be taken as a fairly good indication of the life to be expected with a practice definitely adapted to their use. Some "flaking" seems to occur in the arches with these bricks, but the principal cause of failure in most cases is metal erosion and slag attack on the jambs.

Basic Linings in Greaves-Etchells Furnaces.

The above data all refer to the normal non-conducting-hearth type of furnace. S.S.D. bricks are also being used successfully in the side walls of Greaves-Etchells conducting-hearth furnaces. The following figures are typical of the performance obtained in one such furnace:

Operating Conditions:

Capacity	10/14 cwt.	Nature of charge:	Scrap, turnings, and
Charging	Bucket.		punchings.
Rating	500 kVA.	Steels made:	Carbon, manganese, and alloy.
Duration of heat	$2\frac{1}{2}$ hr.	Slags used:	Oxidizing and reducing.
Temperature at tap	1600° C.	Operation:	Intermittent.

Lining Details:

Bottom	$16\frac{1}{2}$ in. thick conducting hearth.
Side walls	9-in. S.S.D. bricks (1–3-in. chrome-magnesite separating course on top).
Door arch	Silica, $13\frac{1}{2}$ in. thick.
Door jambs	S.S.D. bricks, $13\frac{1}{2}$ in. thick, with 1 course chrome-magnesite next to silica arch.
Tap-hole	S.S.D. bricks with silica arch and chrome-magnesite between.

Lining Life in Heats:

Bottom	1500.
Side walls	120.
Door arch	60 main arch; 16 front arch.
Door jambs	25.
Tap-hole	60 main arch; 16 front arch; 25 jambs.

Causes of Failure:

For the bottom, the main cause of failure is steel penetration. For the side walls, the main cause is said to be disintegration. Mechanical abuse is given as the main cause of wear of the door arch and jambs and the tap-hole, which is also used for charging.

RECOMMENDATIONS FOR LINING BASIC ELECTRIC FURNACES.

Fig. 1 shows the various positions in the electric furnace in which S.S.D. dolomite bricks have proved satisfactory, and indicates the general method of installation recommended.

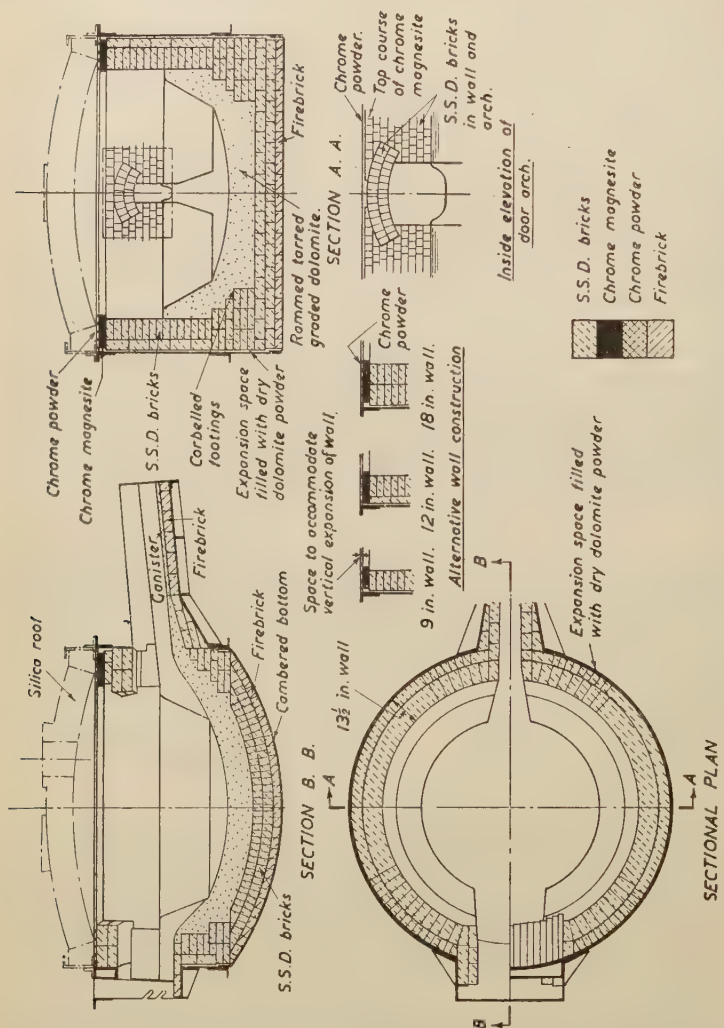


FIG. 1.—Basic Lining in 15-ton 3-phase Direct Series Electric Arc Furnace.

The basic courses under the hearth and the corbelled courses round the sides can be laid with squares or crowns or a combination of these. Most furnace users appear to use squares in the bottom, the joints being filled in with a suitable dry cement when dolomite bricks are used. With cambered bottoms, squares or side-arch bricks laid straight across the bottom can be used. With dishd bottoms the following methods are in use :

(1) Bricking in concentric rings starting from the centre. The disadvantages of this method are that a fair amount of cutting is generally necessary in constructing the central portion and that a considerable number of different shapes must be carried to fit the curvature of the various rings.

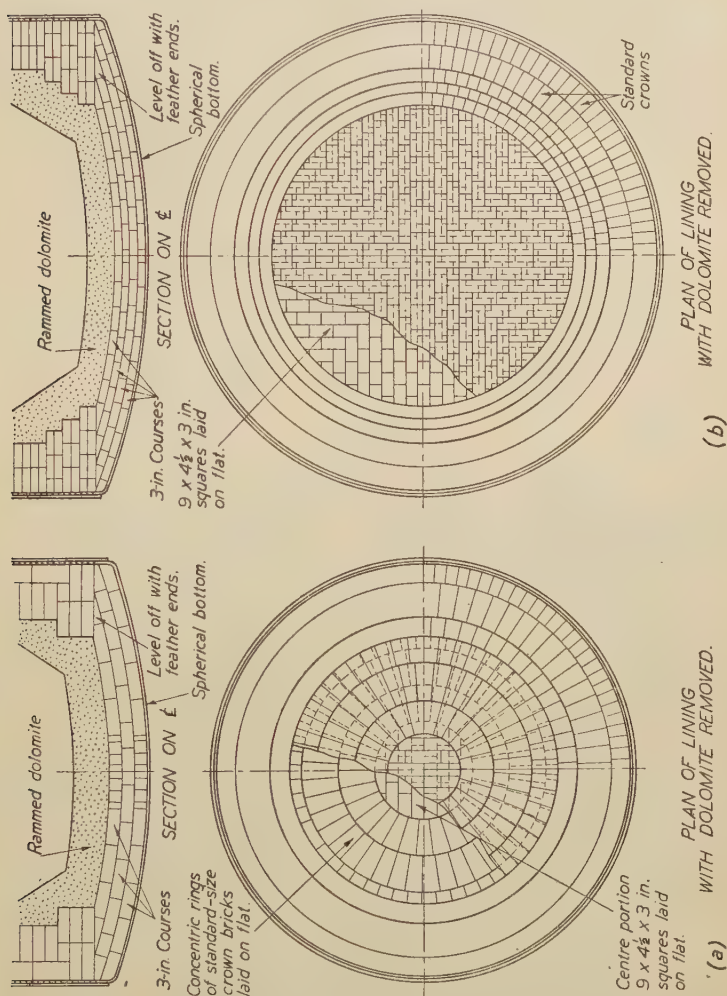


Fig. 2.—Brickwork in (a) 4-ton and (b) 20-ton Arc Furnace Bottoms.

(2) By quartering. Only one size of brick is required, but cutting is generally necessary round the periphery. It is easy to break the bond between courses when using this method, thus avoiding straight-through vertical joints.

(3) Bricking straight across. This method also requires only one size of brick, but cutting is again required round the periphery.

Where methods (1) or (3) are used, the bottom courses can be laid either on the flat or on the edge. The latter method gives smaller spaces at the joints where squares are used, but the ultimate choice depends largely on the thickness of brickwork it is desired to employ under the hearth. Methods (1) and (2) are illustrated in Figs. 2 (a) and (b). Where stable dolomite bricks are used in this position, it is suggested that a course of S.S.D. bricks next to the hearth will give a somewhat greater factor of safety as a result of their greater resistance to slag and metal.

The wall circles are constructed of crowns $9 \times 4\frac{1}{2}/4 \times 3$ in. or $9 \times 4\frac{1}{2}/3\frac{1}{2} \times 3$ in., or of combinations of these, to give circles of the required diameter. Table II. gives the number of each type required to give circles of various sizes.

TABLE II.—*Construction of Circles of Various Diameters.*

Inside Dia., ft.	Number of Bricks Required.	
	$4\frac{1}{2}/4$ -in. Crowns.	$4\frac{1}{2}/3\frac{1}{2}$ -in. Crowns.
12	113	...
11	96	8
10	80	16
9	64	24
8	48	32
7	32	40
6	16	48
5	...	56

Alternatively, combinations of crowns and squares can be used to construct circles of various diameters.

To make up the rest of the thickness of the wall, either a 3-in. or a $4\frac{1}{2}$ -in. backing can be used, this being constructed of squares or side-arch bricks or both laid on end to give the desired size of circle. It is recommended that the joints in the two layers should be staggered both vertically and horizontally as far as possible, so that long vertical and horizontal joints are avoided. Between the shell and the lining a space of $\frac{3}{4}$ -1 in. is left to allow for expansion, this being the only expansion allowance made. It is filled with 100% dolomite dry cement.

At the top of the wall adjacent to the roof, it is desirable to use either one or two courses of chrome-magnesite brick, preferably corbelled about 1 in. with respect to the inner surface of the wall, the object of this being, as previously indicated, to keep roof drips off the basic refractory as far as possible. Where low-chromium steels are being made, however, it is sometimes preferred to keep the chrome-magnesite flush with the wall to minimize the risk of pieces of chrome-magnesite falling into the bath. On top of the chrome-magnesite courses is placed a layer of chromite powder to form a bed on which the roof can rest. Some users consider that this is all that is necessary to prevent reaction between the roof and wall refractories, and they dispense with the chrome-magnesite brick courses, while a few others use no neutral layer at all in this position, though this is not considered a desirable practice.

Where silica is used for the door arches or jambs in conjunction with dolomite-brick walls, it is necessary to insert a layer of chrome-magnesite bricks between the two materials to prevent reaction and fluxing. In building the door and tap-hole arches it is advisable to carry the skew-back of the arch well beyond the jambs into the wall. This ties it more securely into position and furthermore gives an arch which will remain

stable even if the jambs are extensively damaged. The use of a double arch, *i.e.*, two courses of arch bricks on top of each other as indicated in the diagram, is also recommended, as damage to the lower arch will not then bring down the whole structure.

In using S.S.D. bricks, cutting or mechanical abuse during installation should be avoided as far as possible. This recommendation is necessary since, as described later, these bricks rely on tar impregnation for protection against hydration by the atmosphere. Cutting of the bricks will expose unprotected surfaces and hydration will occur. Mechanical damage to the grains by bruising greatly accelerates such hydration. If cutting is unavoidable, the cut surface should be dipped in tar to protect it until such time as the furnace is heated-up.

In all cases where magnesite and S.S.D. bricks are used, they should be laid with dry jointing material because of the risk of hydration occurring, particularly with the latter. Chrome-magnesite bricks, on the other hand,

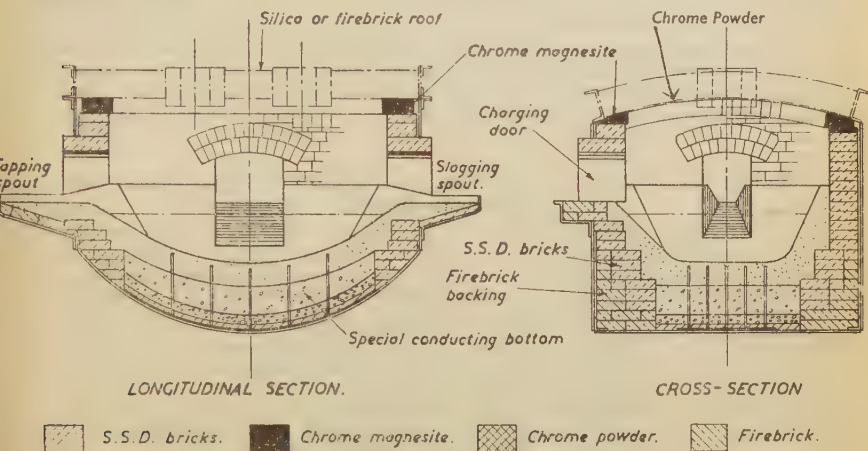


FIG. 3.—Basic Lining in 3-ton Greaves-Etchells Electric Arc Furnace with Conducting Bottom.

can be laid with wet cements, though it should be noted that where such wet-cemented courses are laid underneath or directly adjacent to hydratable bricks, they should be thoroughly dried out before the latter are placed in position, as hydration is likely to occur owing to penetration of moisture from the wet courses, particularly when heat is applied to the furnace.

Fig. 3 shows the method of lining a Greaves-Etchells furnace using S.S.D. bricks. Apart from the hearth, which is, of course, conducting and specially constructed, the general recommendations are similar.

THE UTILIZATION OF DOLOMITE FOR BRICKMAKING.

Attempts to make bricks or blocks from dolomite date from the time when dolomite was first used for lining basic Bessemer converters. Since that time unfired, tar-bonded blocks have been used by some operators for the lining of such converters, but these are made on the spot by the user and installed soon after making. Generally, attempts by brick manufacturers to produce a fired 100% dolomite brick for sale proved unsuccessful until the brick described in the present paper was produced. Many attempts, some successful, have, however, been made to produce a fired dolomite clinker

stabilized against hydration by the addition to the dolomite, before calcination, of substances capable of reacting with the lime at high temperatures to form refractory compounds. It is, of course, necessary to make sufficient addition to ensure that all the lime present shall be combined, if complete stability is to be achieved. The disadvantage of this procedure is that considerable quantities of the addition have to be made and that the additions, though they may still leave the product with adequate refractoriness, will generally markedly increase the amounts of liquid formed when fluxes are picked up in the furnace. A modified method, for which smaller additions are required, is to use normal dolomite clinker but to add to the graded brick-batch sufficient of a lime-combining oxide or mineral to form a coating of a stable, hydration-resisting compound on the surface of the grains on firing. Oil or tar must be used as a bond. Such bricks are not completely resistant to hydration and are often known as "semi-stable" or "bottled" bricks, as the dolomite grains are regarded as being "bottled" by the hydration-resistant compounds. No bricks of this type are apparently made in this country at the present time.

A large number of materials have been suggested, and many patented, as stabilizing additions to dolomite, including bauxite, slag wool, igneous rocks of various kinds, clay, silica, etc. Table III. gives the chief patents taken out in this country since 1910.

TABLE III.—*List of British Patents Relating to the Stabilization of Dolomite Bricks.*

Name.	Patent No.	Year.	Method.
Markan	14,981	1910	Dolomite and bauxite.
Twynam	102,386	1916	Dolomite and slag wool.
Kennedy	111,853	1917	Dolomite and silica.
Rollanson	113,199	1917	Dolomite and silica or clay.
"	156,447	1920	Dolomite and basic slag.
Longbottom & Co.	191,412	1921	Dolomite sealed with wax.
Hodson Bros.	193,576	1921	Dolomite and igneous rocks.
Hodson	211,944	1922	Dolomite and magnesium silicate.
"	218,720	1924	Refinement on 211,944.
Garnett & Co.	197,791	1922	Dolomite and silicate additions.
Duffield	278,120	1926	Fused dolomite and flux.
Sprenger	340,958	1929	Dolomite with chromic oxide, alumina, or silica.
Garnett	368,798	1930	Dolomite and kaolin or labradorite.
Ernould	440,011	1935	Dolomite with chromic oxide, alumina, or silica.
Pitt	450,961	1934	Dolomite and silica with alumina.
Arnold	470,028	1936	Dolomite and serpentine with phosphate rock or boric acid to give calcium ortho-silicate.
Non-Metallic Minerals, Inc.	464,047	1935	Mixture to give merwinite.
" "	475,508	1936	Mixture to give merwinite and stabilized calcium orthosilicate.
Arnold	481,281	1936	Mixture to give merwinite and stabilized calcium orthosilicate.
Richardson	471,373	1936	Dolomite and chloride of aluminium, chromium, &c.
Pitt	492,565	1937	Calcium silicates bonded with alkali salts.
Knocker & Werke	486,490	1937	Slaked dolomite, sintered with iron additions.
Lavino	509,901	1938	Dolomite and silica with stabilizer.
"	510,087	1938	" " " " (Refinement.) "

As is now well known, the stable dolomite clinker produced in this country is stabilized by the addition of finely ground serpentine to the finely ground raw dolomite before firing. The choice of this material has two advantages in that stabilization is effected by silica, which, by virtue of its low molecular weight and its ability to form tricalcium silicate, is capable of combining with more lime, weight for weight, than any of the other suitable oxides, and, secondly, that the magnesia contributed by the serpentine increases the MgO content of the clinker, thus raising its refractoriness and slag resistance. It is thus perhaps the most refractory stable sinter attainable by the use of unprocessed, commonly occurring materials.

Generally, in the British clinker, the addition of serpentine is such that, allowing for alumina, iron oxide, and silica already present in the dolomite or picked up from the fuel ash, the chief lime compound is tricalcium silicate, though some dicalcium silicate generally occurs as well, owing to the necessity of adding a certain excess of silica to ensure complete combination of the lime. The clinker must, therefore, also be stabilized against dicalcium silicate dusting, and this is apparently done by the addition of boric oxide, which probably serves the double purpose of stabilizer and mineralizer. The American literature and patents, on the other hand, generally indicate dicalcium silicate, suitably stabilized, as the chief lime compound in their clinkers. It is, of course, much easier to form dicalcium silicate than tricalcium silicate, which forms only between 1200° and 1900° C. and then rather sluggishly, necessitating intimate mixing and high firing temperatures. Furthermore, as an examination of the relevant thermal equilibrium diagrams will show, a considerable range of compositions in the system $\text{CaO-MgO-Al}_2\text{O}_3\text{-Fe}_2\text{O}_3\text{-SiO}_2$ which contain 3CaO.SiO_2 but no free CaO in the solid state, begin to melt incongruently with separation of lime, so that heating above the minimum temperature of liquid formation cannot promote complete combination of the lime, which can take place only on slow cooling to the temperature of complete solidification. Increasing the iron oxide content, however, relative to the Al_2O_3 content, diminishes the degree of incongruence at melting, and with a high enough ratio of Fe_2O_3 to Al_2O_3 congruent melting is ultimately achieved. It is possibly because of these difficulties that dicalcium silicate is preferred in the American patents. The loss of refractoriness accompanying the higher silica contents necessary can probably be discounted, but the slag resistance may be somewhat lower. Another point of some practical importance to the brickmaker is that clinker rich in tricalcium silicate can readily be bonded with water, as it gives an excellent hydraulic set. Clinkers high in dicalcium silicate, on the other hand, are generally deficient in hydraulic setting.

Production of the S.S.D. Brick.

The S.S.D. brick referred to in the present paper is made from an unstabilized dolomite clinker, *i.e.*, one which has been made without the addition of any substances which would combine with the lime to stabilize it. The reason for this is that, generally speaking, all such additions lower the slag resistance of dolomite by giving lower-melting liquids and greater amounts of liquid when fluxes are picked up at high temperatures. So far at least, no commercially feasible stabilizing additions capable of increasing the slag resistance of dolomite have been found, so that the unstabilized brick represents the maximum slag resistance attainable with dolomite short of treating it to remove lime or of diluting it with magnesite to raise the MgO content. (It may be noted that bricks can be, and have been, made with magnesite additions for the latter purpose, but this is not general practice, since the improvement in slag resistance is not usually very marked until relatively large proportions of magnesite are added.)

Bricks made from such clinker are, of course, susceptible to hydration in the atmosphere and hence have to be given a measure of protection to confer on them reasonable keeping qualities. This is done by impregnating them with a suitable tar, after which treatment they can be stored for periods up to about six months with safety, if they are not exposed to mechanical damage. Laboratory-treated specimens have on occasion been kept under good conditions for periods up to fifteen months without deterioration. Incidentally, impregnation with this tar confers on the bricks enhanced resistance to crushing and mechanical shock at room temperature.

The dolomite clinker used is prepared from a primary dolomite of Permian origin which occurs in the Worksop area, and before delivery at the works it has been dead-burned in vertical shaft kilns. It is generally received in sizes ranging from 1 to 4 in. in dia. From each 10-ton wagon a 3-cwt. sample is withdrawn, and the percentage of underfired material is estimated by picking out all the obviously unvitified material, which together with the fines passing a 16-mesh B.S.S. screen, is classed as underfired or soft-fired. Such material has a much lower bulk density than the well-fired material, as shown by the figures given in Table IV. which were obtained from actual consignments.

TABLE IV.—*Density of Hard- and Soft-Fired Dolomite.*

Bulk Density.		Content, %.	
Hard-Fired.	Soft-Fired.	Hard-Fired.	Soft-Fired.
2.85	2.04	85	15
2.86	1.94	86	14
2.78	1.98	80	20
2.94	1.92	93	7
2.81	1.70	98	2
2.74	1.72	97	3
2.89	1.61	95	5
2.81	...	98	2
2.82	...	99	1

Clinker with more than 5% of soft-fired material is considered unsatisfactory, while it is considered that the minimum bulk density of the hard-fired material should be 2.80. Bulk densities are determined on $\frac{1}{2}$ -in. + $\frac{1}{4}$ -in. pieces, using a mercury volumeter.

Chemical analyses carried out on the brick batch indicate that the contents of the various constituents lie within the following ranges:

SiO ₂ , %.	B ₂ O ₃ , %.	CaO, %.	MgO, %.	Loss on Ignition, %.
4.50-1.20	4.80-2.70	58.00-53.20	41.00-36.20	1.90-0.20

Typical analyses and properties of S.S.D. bricks are given in Table V., together with those of other refractories currently used in electric furnaces.

FACTORS DETERMINING THE LIFE OF S.S.D. BRICKS IN BASIC ELECTRIC FURNACES.

Normally the life of an electric-furnace lining is determined by the rate at which it wears back to the point where replacement is considered necessary. This wear may be the result of several factors operating at, or behind, the working face, *e.g.*, fluxing or melting, bursting, "flaking,"

TABLE V.—*Chemical Analyses and Physical Properties of Refractories used in Basic Electric Furnaces.*

	Silica.	Sillimanite.	Firebrick.	Magnesite.	Chromite.	Chrome-Magnesite.	Stable Dolomite.	S. S. D. Brick.
Chemical Analysis :								
SiO ₂ , %	+ 95	34.4	54.8	2/3	4/8	4/6	13/15	3/5
TiO ₂ , %	...	1.5	1.0	0.1	0.2	0.2	0.2	0.2
Al ₂ O ₃ , %	...	63.0	41.5	1/3	16/20	14/20	2/3	1/3
Fe ₂ O ₃ , %	...	0.90	2.0	2/8	12/15	10/14	2/4	1/3
Cr ₂ O ₃, %	...	...	...	...	34/40	22/30	...	...
FeO, %	...	...	...	...	...	...	...	...
MnO, %	...	...	...	0.1	0.2	0.1	0.1	0.1
CaO, %	1.5/2.0	...	0.7	1/5	1/3	1/3	36/40	48/50
MgO, %	...	...	0.5	85/90	12/20	38/40	38/40	38/40
Physical Properties :								
True porosity	20/22	22	25	20/22	22/24	22/25	22/25	24/25
Apparent porosity	20/22	19	22	19/21	20/22	22/24	21/24	23/24
Bulk density	1.8/1.9	2.35	1.9/2.0	2.9/2.88	3.1/3.2	2.35	2.5/2.6	2.5/2.6
Sp. gr.	2.34/2.36	3.00	2.60	3.5/3.6	3.9/4.1	3.8	3.4	3.34
After contraction (2 hr./1500° C.)	0.1/0.2	0.1/0.3	0.3/0.4 (1400° C.)	0.1/0.5	0.3/0.5	0.1/0.2	0.2/0.7	0.2/0.5
Spalling index	...	+30	...	6	4	+30	4/6	+15
Cold crushing strength, lb./sq.in.	...	+6000	+4000	+6000	+6000	3000	6000	4000
Reversible thermal expansion (× 105)	1.25	0.45	0.60	1.20	0.90	1.00	1.20	1.10
Permeability	0.1	0.05	0.2/0.8	0.05	0.05	0.07/0.2	0.1	0.2
Refractoriness-under-load, lb./sq.in.	(50)	(28)	(28)	(28)	(28)	(28)	(28)	(28)
Subsidence began, ° C.	1670	1620	1500	1500	1340	1600	1450	1500
Fail by shear, ° C.	1700	1720	1620	1600	1400	+1700	1650	1600
Maintained load test (2 hr.), lb./sq.in.	(50)	(28)	...	(28)	...	(28)	(28)	(28)
1500° C.	Nil	1%	...	3%	...	Nil	3%	7%
1550° C.	Nil	1.5%	...	(90 min.)	...	2/4%	(70 min.)	7%
1600° C.	2%	2%	...	...	...	5%	...	...

structural spalling, and ordinary thermal spalling. In the case of S.S.D. brick linings, experience in service and the replies to the questionnaire circulated to users indicate that the principal factors are generally fluxing of the working face and "flaking" or splitting-off behind the working face, the latter allowing pieces of brick usually between 1 and 2 in. thick to fall away. The former is a continuous process and can be regarded as a more or less intrinsic property of a given refractory in a given environment, though it is, of course, influenced to a considerable degree by such factors as the texture, porosity, and bulk density of the refractory, and by variations in the impurities or secondary materials present in it. The latter is common to all basic refractories. It is intermittent and recurrent. With S.S.D. bricks the severity of its onset appears to vary considerably with different practice and with different positions in the furnace. In particular the lack of adequate support of the working face from below, such as occurs where the bricks are used in overhanging positions or when undercutting takes place in a side wall, will increase the incidence of flaking.

For some time past an investigation into the factors determining the performance of S.S.D. bricks in basic electric furnaces has been in progress. This investigation is not yet completed (indeed its scope if pursued in all its aspects is a very wide one), but it seems opportune to give some account of it in the present paper. Among the aspects to be considered have been the nature of the fluxes picked up by the refractory and the manner of their transfer to its surface, the effect of the alternating oxidizing and reducing atmospheres, and the mechanism of flux attack on the refractory.

General Observations from the Examination of Used S.S.D. Samples.

A considerable number of used, partly slagged S.S.D. bricks from linings have been examined both externally and in section, and generally distinct evidence of zoning has been observed (Fig. 4). The main features of the various zones as observed on samples varying from almost the full 9 in. to approximately 5 in. in length are as follows:

Zone 1.—Adjacent to and forming the working face is a dark zone generally approaching $\frac{1}{2}$ in. in thickness and evidently highly charged with iron oxide. When fully developed it is extensively fused and vesicular, showing no trace of the original brick structure, and often there are indications that flow, or, in some cases, slumping of the fused mass as a whole, has been occurring at the working temperature. In the latter case the development of what appear to be "hot tears" is generally evident. This condition represents a limiting state indicating that flux pick-up has reached the point at which cohesion is lost and flow starts. Tearing probably occurs when the mass as a whole is inadequately supported from below. Some of the samples examined gave indications that flaking had recently occurred, and showed this zone in various stages of development short of the limiting state.

Zone 2.—Many of the samples examined "dusted" on cooling, in a very narrow zone immediately behind Zone 1. This was consequently denoted Zone 2, though before dusting there was no visual indication of its presence, as it was as dark as Zone 1. The powder after dusting appeared considerably lighter. When dusting of this zone occurs, it causes Zone 1 to fall away from the rest of the brick. This is of no importance at working temperatures, as the β to γ transformation in dicalcium silicate occurs only on cooling below 675° C. Furthermore, under ordinary conditions of cooling, it is very often necessary to cool considerably lower than this temperature before dusting occurs. If, however, a furnace is cooled right down for repairs, loss of the working face due to dusting is liable to occur with an appreciable proportion of the bricks, the thickness lost being, on the average, about $\frac{1}{2}$ in. A point of interest is that no dusting was observed in

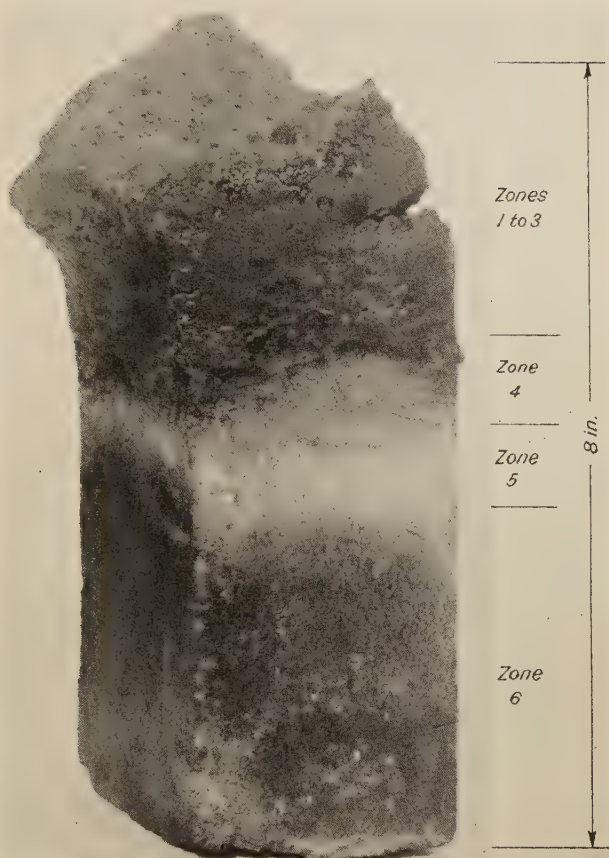


FIG. 4.—S.S.D. Brick from Side Wall of Electric Furnace with S.S.D. Roof after 57 Heats. Face nearest camera has been ground. Sample is complete, no dusting having occurred on cooling. Average length over 8 in. Some slumping has taken place at the hot face owing to undercutting.

[Brampton and others.

[To face p. 360 p.



FIG. 5.—Typical Appearance of Portion of S.S.D. Brick Detached by Flaking. Hot face is on left.

[*Brampton and others.*]

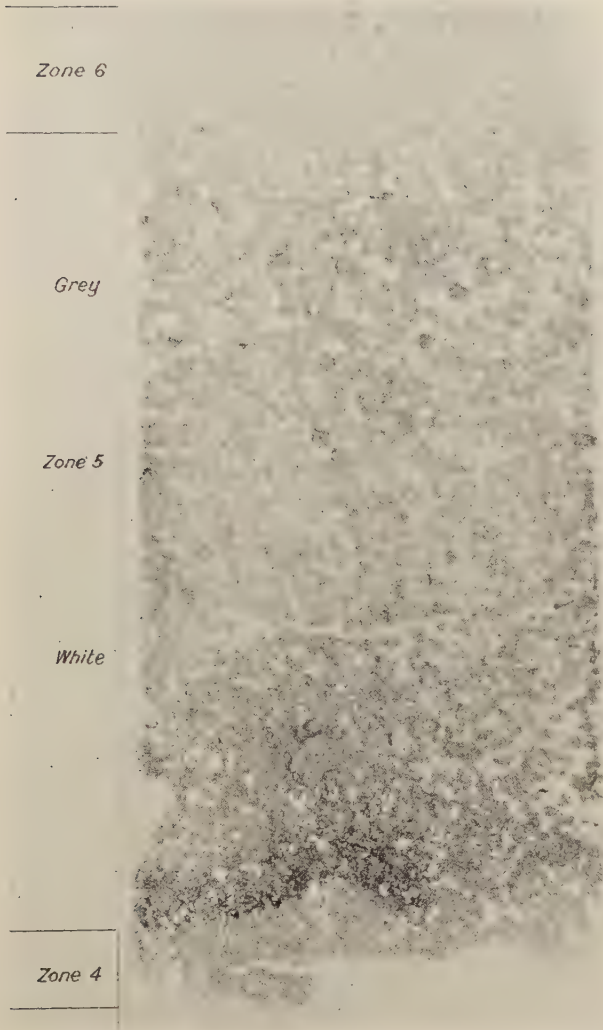


FIG. 6.—Sulphur Print of Portion of Used S.S.D. Brick, showing concentration of sulphide in Zone 5.

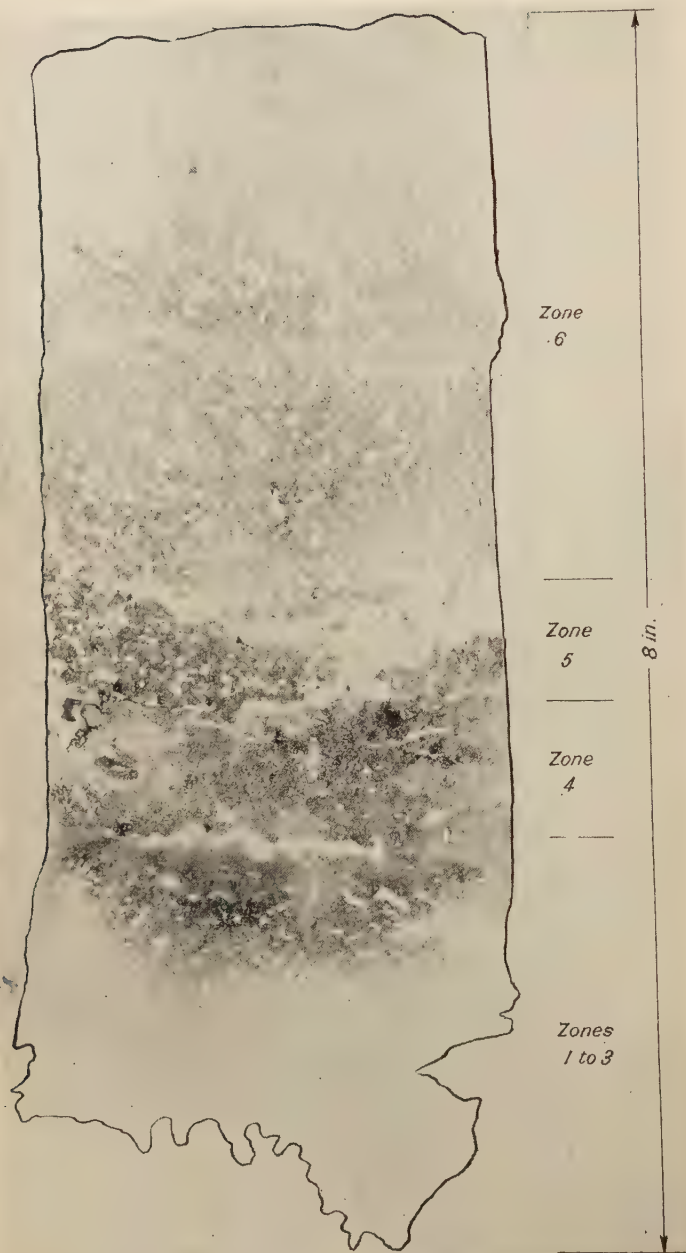


FIG. 7.—Sulphur Print of Complete Section of Used S.S.D. Brick.

[Brampton and others.
[To face p. 361 P.

the side-wall bricks which had been used in conjunction with the S.S.D. roof trial previously described, indicating that a considerable proportion of the silica picked up by S.S.D. linings comes originally from the silica roof.

Zone 3.—This is another dark, almost black, zone which differs visually from Zone 1 in that it appears to have retained its rigidity, and consequently the original shape of the brick section, at working temperatures. In electric-furnace samples this zone may still show traces of the original brick structure. In samples taken from the back wall of an open-hearth furnace, on the other hand, this zone, while lighter in colour than Zone 1, had lost all trace of the original brick structure and had developed a dense, "stony," almost porcelain-like texture, practically free from pores. It had still, however, retained sufficient rigidity to maintain its form and cohesion at working temperatures. This behaviour appears to be characteristic of the fluxing of dolomite and is discussed later. In both the electric-furnace and the open-hearth samples, Zone 3 terminated abruptly at a sharp line of demarcation, the next zone being much lighter in colour. This suggests a temperature restriction of some kind on the diffusion of iron oxide into the brick. The distance of this limit from the working face was found to be between $1\frac{1}{2}$ and 2 in.

Zone 4.—This was a rather pale yellow-brown zone and varied somewhat in width in different samples. It still retained the original granular texture of the brick, but there had apparently been appreciable fluxing, as the fractured surfaces had a "waxy" vitrified appearance.

Zone 5.—This was a white to light-grey zone of varying width, which showed the original structure of the brick practically unchanged, but apparently strongly reduced. This tended to be the weakest zone mechanically in the used bricks, and they often broke through it or between it and Zone 4 when an attempt was made to cut them with a chisel. It was also easier to crush than the other zones.

Zone 6.—This was a dark zone extending to the back of the brick and having a rather poorly defined boundary with the white zone. The blackening is apparently due mainly to carbon or carbonaceous matter left as residues after the cracking and distillation of the tar in the original brick, and protected from oxidation by the furnace shell. The texture of this zone, like that of Zone 5, is essentially that of the original brick.

All the samples came from linings which had completed their working lives normally and so had been last subjected to the reducing conditions prevailing during the refining periods of their final heats. It seems likely that fusion and slumping of Zone 1 will be accentuated during this period, as described later.

Several of the samples showed flaking at various stages of development. In all these the fracture was found to have occurred either in Zone 3 or in the region of the interface between Zones 3 and 4. Sometimes it passed partly through Zone 3 and partly through Zone 4. In most cases where fracture was incomplete it could be seen that the portion flaking off had slumped or bulged away from the main part of the brick over the area of the fracture, indicating that the material had been appreciably plastic at the working temperature. In several samples a number of smaller "hot tears" could be seen in Zones 1 to 3, starting at what had obviously been the upper surface of the brick. These observations, together with the general appearance of the fracture, suggested that flaking is associated with a loss of hot strength consequent on the penetration of fluxes and liquid formation. This is in agreement with the observation that flaking appears to be aggravated when the working face of the brick is inadequately supported from underneath. At the same time, however, there are indications that other factors may be involved. For one thing, the common location of the

fracture at or near the interface between Zones 3 and 4 may be an indication that stresses due to differential expansion or contraction are a factor. Further, the surface of the fracture is very often convex towards the working face, suggesting (since no appreciable shrinkage of the material behind the fracture has been detected) that the part flaking off may have tended to expand. (See Fig. 5.) Again, where flaking off was incomplete it was generally found that the last remaining adhesion was provided by two strips adjacent to the 9×3 -in. faces of the brick. In such cases, as mentioned above, it was often noted that the central portion where separation was complete had bulged away from the main part of the brick. These observations are consistent with the view that expansion of the flaked portion was occurring, but that movement of the edges could not take place, either because of the constraint of neighbouring brickwork or because stronger adhesion existed adjacent to the faces mentioned. "Arching" of the centre would then tend to occur following fracture. It is difficult to prove this conclusively from the examination of used bricks, however, as the mere fact of such constraint would mean that little if any difference in dimensions, as measured between opposite faces, would arise. One other point in connection with possible volume changes deserves mention. The opinion has sometimes been expressed that S.S.D. bricks tend to shrink in the furnace. No indication of this has, however, been obtained from the measurement of used bricks having the zones fully developed. Some shrinkage may, however, occur at the surface during the initial stages of flux pick-up.

A striking feature of the fluxing of dolomite emerged from the examination of the various samples, namely, that the dolomite grains tend to lose their identity before complete loss of rigidity occurs. The reason for this lies apparently in the duplex nature of the dolomite grains. In the presence of fluxes the lime crystals react more readily than the periclase crystals, and allow penetration of the fluxes inside the grains. The effect of this is often observed, in examining samples of partly fluxed dolomite under the microscope, in the form of clusters of small periclase grains separated from one another by a dark infilling material which has evidently been liquid at high temperatures. The effect throughout is apparently to cause the grains to disintegrate to give a semi-liquid mass containing minute periclase and possibly undissolved lime crystals dispersed in it. Ultimately, as migration of the fluxes and fluxing products proceeds, all semblance of the original grains and pores is lost, as previously described. This tends to occur to a marked extent in Zones 1 to 3 and to a lesser extent in Zone 4. Incidentally, this behaviour of the dolomite grains with regard to fluxes probably accounts for a characteristic feature of most of the flakes and "hot tears" examined, namely, that, even when the form of the original grains could still be detected, the tears or fractures passed impartially through grains and matrix as though through an isotropic material. This is apparently due to the penetration of the fluxes into the grains, which lowers the internal cohesion within them till it is no greater than the cohesion existing between the grains.

On a few of the samples a tendency to cracking or spalling was noted further back from the hot face. These cracks were generally situated near or at the junction of the yellow vitrified Zone 4 and the grey-white unvitrified Zone 5. In some cases it appeared as though they might have been formed during the final cooling of the brick, and their appearance suggested that a form of spalling was involved, due presumably to the existence of stresses within the brick in the neighbourhood of the junction between these zones, and aggravated possibly by the relative weakness of Zone 5. In any case, there were no indications that this had had any adverse effect on the lives of the bricks affected.

Examination of Flaked Portions of S.S.D. Bricks.

To investigate the nature of the reactions occurring in the vicinity of the working face, and to provide information on the influence of the changing atmospheric conditions in the furnace on the partly fluxed refractory, portions of brick were removed from an 8-ton furnace (a) at the end of the oxidizing period, *i.e.*, at slagging, and (b) at the end of the reducing period, *i.e.*, at tapping. For this purpose portions which were on the point of flaking off were detached with a bar and caught before they fell into the bath. The furnace had previously done 23 heats. Both specimens dusted immediately behind the working face on cooling. Examination showed that the zones present corresponded to Zones 1, 2, and 3, with what appeared to be portions of the lighter-coloured Zone 4 immediately adjacent to the surface of flaking. It was noted that Zone 1 on the slagging specimen was represented by a rather loosely adherent, structureless black mass showing evidence of flow or drainage in its surface contours and with a maximum thickness of about half an inch. It had a glistening appearance, suggesting the presence of a crystalline phase, and was strongly magnetic. On the tapping specimen Zone 1 was more compact and adherent and, on the average, thinner. It was also duller in appearance and vesicular and showed evidence of flow at the surface. It was only moderately magnetic. These observations suggest that there may be appreciable building up of this zone during the oxidizing period, followed by accelerated fusion and flow during refining. The appearance of the other zones was as already described and does not call for further comment except to remark that Zone 3 on both specimens still showed the original brick structure, though it was somewhat modified by flux penetration.

Four examples were taken from each specimen, namely, samples of Zone 1, of Zone 2, of the portion of Zone 3 nearest the dusted surface, and of the portion of Zone 3 nearest the flaked surface. The last also possibly contained portions of Zone 4, as indicated above. The samples were designated samples 1, 2, 3A, and 3B respectively. They were subjected to chemical analysis and to microscopic and X-ray examination. The results obtained are given in Tables VI. and VII.

The most significant points arising from the analytical data are as follows:

The principal materials picked up in the furnace were evidently iron oxides, SiO_2 , Cr_2O_3 , MnO , and sulphur. Pick-up of Al_2O_3 is also probably, but perhaps not definitely, indicated, though migration and concentration of material present in the original brick could perhaps account for the values

TABLE VI.—*Chemical Analyses of "Flaked" Portions of S.S.D. Bricks.**

Carried out in the laboratories of the British Refractories Research Association.

Zone :	After Oxidizing Period.				After Reducing Period.			
	1.	2.	3A.	3B.	1.	2.	3A.	3B.
SiO_2 , % . . .	6.12	15.39	6.84	5.05	10.24	15.20	6.78	5.56
TiO_2 , % . . .	0.14	0.33	0.12	0.19	0.26	0.11	0.16	0.39
Al_2O_3 , % . . .	1.54	0.78	1.32	3.09	1.52	1.23	1.83	4.95
Fe_2O_3 , % . . .	30.48	8.38	3.99	4.14	10.27	5.45	2.88	1.22
FeO , % . . .	6.60	6.46	6.30	4.27	17.80	8.94	6.55	2.46
MnO , % . . .	3.74	1.55	0.36	0.08	1.86	1.47	0.45	0.08
CaO , % . . .	12.78	35.99	53.00	53.70	14.46	35.33	53.30	51.40
MgO , % . . .	31.42	29.98	27.65	28.98	42.49	31.73	27.38	31.93
Cr_2O_3 , % . . .	7.30	0.69	Trace	Trace	1.00	0.18	0.02	N.d.†
SO_2 , % . . .	0.09	0.45	0.43	0.72	0.18	0.20	0.40	1.21

* Corrected for loss on ignition.

† N.d. = not determined.

TABLE VII.—*Constitution of "Flaked" Portions of S.S.D. Bricks.*

	Phases Observed under Microscope.*	Phases Identified by X-Rays.*	Calculated Constitution (Mg.-mol./100 g.)†
Zone 1.	Periclase stained yellow. Opaque, magnetic spinel. $2\text{CaO} \cdot \text{SiO}_2$, β (?) White's test negative.	<i>After Oxidizing Period.</i> Periclase solid solution $A_0 = 4.210 \text{ \AA.}$ Spinel $\beta\text{-}2\text{CaO} \cdot \text{SiO}_2$	$2\text{CaO} \cdot \text{SiO}_2$ 0.102 " $2\text{CaO} \cdot \text{R}_2\text{O}_3$ " 0.012 Spinel ($\text{RO} \cdot \text{R}_2\text{O}_3$) 0.24 Periclase solid solution 0.683
Zone 2.	Periclase stained yellow. $\gamma\text{-}2\text{CaO} \cdot \text{SiO}_2$. Brownmillerite. White's test negative.	Periclase solid solution $A_0 = 4.215 \text{ \AA.}$ $\gamma\text{-}2\text{CaO} \cdot \text{SiO}_2$ Brownmillerite	$2\text{CaO} \cdot \text{SiO}_2$ 0.257 " $2\text{CaO} \cdot \text{R}_2\text{O}_3$ " 0.050 Periclase solid solution 0.855
Zone 3A.	Periclase. $3\text{CaO} \cdot \text{SiO}_2$. Brownmillerite. White's test positive.	Periclase solid solution $A_0 = 4.203 \text{ \AA.}$ Lime solid solution $A_0 = 4.775 \text{ \AA.}$ $3\text{CaO} \cdot \text{SiO}_2$	$3\text{CaO} \cdot \text{SiO}_2$ 0.114 $4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$ 0.013 $2\text{CaO} \cdot \text{Fe}_2\text{O}_3$ 0.012 CaO 0.927 Periclase solid solution 0.776
Zone 3B.	Periclase. Lime. $3\text{CaO} \cdot \text{SiO}_2$. Brownmillerite White's test positive.	Periclase solid solution $A_0 = 4.200 \text{ \AA.}$ Lime solid solution $A_0 = 4.792 \text{ \AA.}$ $3\text{CaO} \cdot \text{SiO}_2$	$3\text{CaO} \cdot \text{SiO}_2$ 0.034 $4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$ 0.026 $3\text{CaO} \cdot \text{Al}_2\text{O}_3$ 0.005 CaO 0.590 Periclase solid solution 0.779
Zone 1.	Periclase stained yellow. Opaque, magnetic spinel. Merwinite colourless to yellow, forming matrix round crystals of periclase and spinel. White's test negative.	<i>After Reducing Period.</i> Periclase solid solution $A_0 = 4.240 \text{ \AA.}$ Spinel Merwinite	$3\text{CaO} \cdot \text{MgO} \cdot 2\text{SiO}_2$ 0.033 $2\text{CaO} \cdot \text{SiO}_2$ 0.005 Spinel ($\text{RO} \cdot \text{R}_2\text{O}_3$) 0.086 Periclase solid solution 1.240
Zone 2.	Periclase stained yellow. $\gamma\text{-}2\text{CaO} \cdot \text{SiO}_2$. $3\text{CaO} \cdot \text{SiO}_2$. Brownmillerite. White's test negative.	Periclase solid solution $A_0 = 4.220 \text{ \AA.}$ $\gamma\text{-}2\text{CaO} \cdot \text{SiO}_2$	$3\text{CaO} \cdot \text{SiO}_2$ 0.032 $2\text{CaO} \cdot \text{SiO}_2$ 0.221 [$4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$] [$2\text{CaO} \cdot \text{Fe}_2\text{O}_3$] 0.012 Periclase solid solution 0.022 0.430
Zone 3A.	Periclase stained yellow. Lime. $3\text{CaO} \cdot \text{SiO}_2$. Brownmillerite.	Periclase solid solution $A_0 = 4.215 \text{ \AA.}$ Lime solid solution $A_0 = 4.775 \text{ \AA.}$ $3\text{CaO} \cdot \text{SiO}_2$	$3\text{CaO} \cdot \text{SiO}_2$ 0.113 $4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$ 0.018 CaO 0.541 Periclase solid solution 0.776
Zone 3B.	Periclase. Lime. $3\text{CaO} \cdot \text{Al}_2\text{O}_3$. $3\text{CaO} \cdot \text{SiO}_2$. Brownmillerite.	Periclase solid solution $A_0 = 4.207 \text{ \AA.}$ Lime solid solution $A_0 = 4.796 \text{ \AA.}$ $3\text{CaO} \cdot \text{Al}_2\text{O}_3$ $3\text{CaO} \cdot \text{SiO}_2$	$3\text{CaO} \cdot \text{SiO}_2$ 0.093 $4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$ 0.008 $3\text{CaO} \cdot \text{Al}_2\text{O}_3$ 0.132 CaO 0.486 0.825

found. This seems rather unlikely, however, in view of the relatively high concentrations indicated in some zones. It may, however, apply to the TiO_2 contents shown. It is, of course, impossible to say whether any pick-up of CaO or MgO occurred owing to the prevalence of both in the original brick. Some deposition of both on the refractory surface in the furnace is to be expected, however.

The different materials picked up show different powers of penetration and tend to reach maximum concentration in different zones. Of the constituents reported, Cr_2O_3 has penetrated the least and its concentration drops rapidly beyond Zone 1. The concentration of MnO also drops rather rapidly beyond Zone 1, while the iron oxides, though their concentration drops regularly with distance from the hot face, have penetrated to Zone 3B in considerable amounts. Silica has also penetrated to the flake, but its concentration reaches a definite maximum in Zone 2. In taking the sample for this zone some concentration of SiO_2 may have occurred, as only the powder produced by dusting was taken. It was necessary to do this since some fragmentation of adjacent portions of Zones 1 and 3 had occurred during dusting. However, since dusting occurred only in Zone 2, there is little doubt that a maximum concentration of silica is reached in this zone. The behaviour of Al_2O_3 and, to a lesser degree, TiO_2 appears to be specially significant. After an initial tendency to decrease somewhat from Zone 1 to Zone 2, they show a definite tendency to increase towards the flake. It appears that they must be largely responsible for the fluxing seen in the light-coloured Zone 4. This point is further discussed below. Sulphur increases progressively from the hot face to the surface of the flake. The CaO and MgO also show definite variations. The contents of these oxides in the original brick would be 37–38% of MgO and 51–52% of CaO , and in both slagging and tapping specimens Zone 1 and Zone 2, though particularly the former, have become very much impoverished in CaO , owing, presumably, to drainage of fusible CaO -rich liquids from the brick, and also, possibly, to creeping of such liquids into the brick. The amount of CaO migrating into Zone 3 can be estimated simply, if it be assumed that no migration of MgO has occurred. For example, taking the analysis of Zone 3B of the oxidized sample, and assuming that the drop in the concentration of the MgO to 28.98% was due entirely to dilution, *i.e.*, that no migration of MgO occurred, dilution in the same degree would have caused the CaO concentration to drop to 38.7%. Hence the remaining 15% of CaO must represent material that has migrated into this zone. Similar calculations can be carried out for the other zones. The possibility of migration of MgO cannot perhaps be entirely ruled out, however (it seems possible that it may have migrated to some extent towards the hot face), and hence the estimates so obtained may be too high. It seems fairly

Notes to Table VII.

* The term brownmillerite is used to refer to any member of the brownmillerite-dicalcium ferrite solid-solution series.

† As the distribution of the sesquioxides and divalent oxides between the spinel, free oxide, and brownmillerite-calcium ferrite phases cannot be determined, it is not possible to state the constitution accurately in terms of weight percentages. It is, therefore, stated in terms of gram-molecules which, however, are readily convertible into approximate weight percentages.

For a similar reason, the relative proportions of Al_2O_3 and Fe_2O_3 in the sesquioxide available for ferrite-brownmillerite formation cannot be determined when spinel is present. Therefore, where spinel occurs the brownmillerite-dicalcium ferrite phase is given in terms of a purely hypothetical " $2\text{CaO}.\text{R}_2\text{O}_3$ " molecule. Two such molecules will be required to form one brownmillerite molecule. The same convention is adopted in dealing with this phase in Zone 2 of the oxidized specimen, since appreciable Cr_2O_3 is present. For simplicity it is assumed that the rather small amount of Cr_2O_3 present will occur as a substitute for Al_2O_3 and Fe_2O_3 in this phase.

certain, however, that appreciable migration of CaO into the brick does occur.

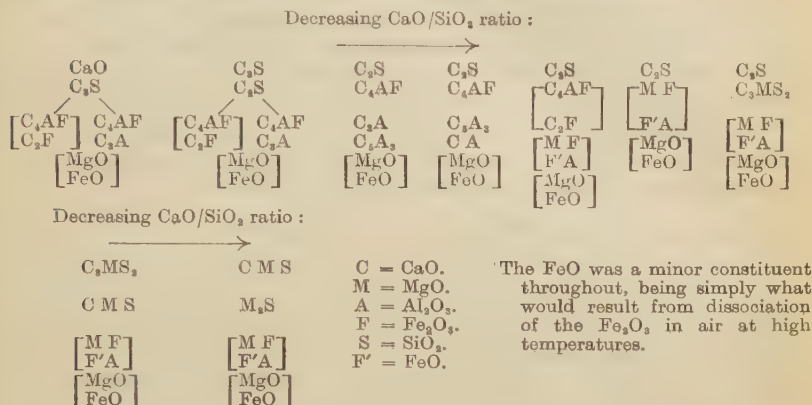
Comparison of the ratios of ferrous oxide to ferric oxide in the various zones of the two specimens shows that the tapping specimen has undergone considerable reduction relative to the slagging sample. (Zone 3.4 of the slagging sample seems somewhat abnormal in this respect, but the indication from the others is definite.) It is clear, therefore, that refractories containing iron oxides undergo alternating oxidation and reduction in the electric furnace. This is likely to have an important influence on refractory life as by reduction the fluxing action of the iron oxide will be increased and the melting point of the fluxing products lowered. It will be noted also that the oxidation and reduction are not confined simply to the hot face. In this connection the fact that with dolomite all the zones nearest the hot face contain appreciable liquid at working temperatures may be of some advantage, since, were the iron-oxide-containing products mainly solid and the zones affected rigid, volume changes might be expected to occur within the brick which might lead to rapid disintegration and spalling. This may be a factor in the relatively short lives given by magnesite and chrome-magnesite in electric-furnace linings, though both are highly refractory and possess high resistance to fluxing.

The microscopic observations summarized in Table VII. were carried out on the powdered samples, using immersion liquids to determine the refractive indices; generally, however, no attempt at exact determination was made, it being desired merely to identify the principal phases. The X-ray photographs were taken with copper $K\alpha$ radiation where this was possible, or where this led to the development of excessive background, cobalt $K\alpha$ radiation was used. No photometer was available, so that only phases with patterns sufficiently distinctive to be separable visually by ordinary measurements were identified. This provided no difficulty in the case of the spinels and free-oxide phases, but was more difficult with the other phases, and careful comparison with previously prepared standards was necessary. The identification of these phases was based mainly on the lower order reflections. The lattice constants of the free-oxide phases were determined by the usual extrapolation against $\cos^2 \theta$.¹ This could not be done for the spinel phase in the Zone 1 samples, as the high-order lines were not sufficiently developed.

Comparison of the phases identified in the various zones with the chemical composition of these zones shows that the phase groupings indicated and the changes in the groupings resulting from changes in composition are in agreement with the system of phase assemblages recently published by Rait and Goldschmidt² for basic open-hearth and basic electric oxidizing slags. In terms of its principal constituents the system to which the present samples belong is somewhat simpler than the one represented by their slags, but direct comparison is, of course, possible, since the relationships in the simpler system are implicit in those of the more complex. To throw light on the compounds occurring in basic refractories in general, and on their slagging products, certain fields of the systems $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2$ and $\text{CaO-MgO-Al}_2\text{O}_3\text{-Fe}_2\text{O}_3(\text{FeO})\text{-SiO}_2$ are being investigated. The method employed has been to make up mixtures lying on possible tie-lines or sections of these systems to find out if they have any actual existence in the system, *i.e.*, to find if the phases involved are compatible with one another. The mixtures were prepared by intimately mixing the pure oxides and firing to just below, or in some cases just above, the onset of melting. The latter method, which was used for expediency is admittedly open to criticism, since the presence of a liquid phase in equilibrium with solid phases may result in errors where incongruent melting occurs. Nevertheless, the results obtained so far by means of microscopic and X-ray

identification of the phases occurring agree with the phase assemblages deduced by Rait and Goldschmidt from their observations on furnace slags and synthetic mixes.

In the system $\text{CaO-MgO-Al}_2\text{O}_3\text{-Fe}_2\text{O}_3(\text{FeO})\text{-SiO}_2$ the phase groupings indicated, in order of decreasing CaO/SiO_2 ratio, are as follows :



These groupings are in complete agreement with the data of Rait and Goldschmidt. One of the most significant features is the critical nature of the ratio of CaO to SiO_2 . If this is greater than 2 to 1 molecularly, brownmillerite and dicalcium ferrite or brownmillerite and calcium aluminates occur. If it is less than 2 to 1, substituted calcium silicates appear and the ferrites and aluminates are absent. It is on these phase groupings that the calculated constitutions of the various zones given in Table VII. are based. Such calculations assume, of course, that the equilibrium phases were formed and this seems to have been the case, as there is agreement between the observed and the calculated constitutions.

Among the significant points revealed by the data in Table VII. is that, as a consequence of the drainage and migration of lime from the vicinity of the hot face, Zone 1 consists mainly of spinel and periclase solid solution, a highly refractory combination. To this is attributable the relatively high resistance to fluxing displayed by the working face of dolomite bricks. No free CaO could be detected in Zones 1 and 2 of either specimen. On the other hand, the increase in Al_2O_3 in Zone 3 results in an increase in the amount of relatively fusible Al_2O_3 -containing compounds in this zone and may be related to the preferential occurrence of flaking towards the back of this zone. (See below.)

The variation in the lattice constants of the free-oxide solid solutions, as revealed by the X-ray data, is also significant. Firstly, as the FeO and MnO contents of the various zones decrease, the lattice constant of the periclase decreases and that of the lime increases, indicating less of these oxides in solid solution. In the case of the lime phase, however, in interesting point arises in that the contraction of the lattice is appreciably greater than could be ascribed to the MnO alone, even if all the MnO reported were dissolved in it. Hence some of the FeO must be present in solid solution in the lime, thus confirming the opinion previously expressed by Jay (private communication) that there is appreciable solubility of FeO in CaO . The second point is that the lattice dimensions of the periclase solid solution tend to be consistently higher in the reduced samples than in the oxidized samples, showing that the effect of reduction is to cause an

increased entry of FeO into the periclasé. This is similar in nature to the effect observed in basic electric oxidizing slags by Rait and Goldschmidt, who found a variation in the lattice constant of the free-oxide phase at different stages of the refining process. In their case, however, reduction was from divalent oxide to metal, so that the lattice constant decreased on reduction. In the present case reduction is from Fe_2O_3 to FeO, which enters the periclasé and increases the lattice dimensions. In the case of Zone 1 this increase will be accompanied by a corresponding change in the spinel phase, which contains the bulk of the sesquioxides. Thus reduction of Fe_2O_3 in the spinel will cause separation of divalent oxides from this phase and increased solution of these in the periclasé. On re-oxidation, FeO in the latter will oxidize and become available for spinel formation. Thus there was considerably less spinel, and more FeO in the periclasé, in the reduced sample than there was in the oxidized sample.

Investigation of Zones Formed in a Used Brick from a S.S.D. Lining.

To supplement the information obtained from the examination of the samples described above, and in particular to throw light on the penetration of fluxes beyond the point at which flaking occurs, the remaining portion of a brick from a used lining was sampled at various distances from the hot face and the samples were analysed. The brick chosen was 5.4 in. long and Zones 1 and 2 had become detached, owing to dusting of the latter, but this was not considered a drawback since these zones had already been studied in the previous specimens. It contained the dark-coloured Zone 3 and the yellowish Zone 4, the rest of the brick being mainly the white to light-grey Zone 5, except for a small zone at the back darkened by carbonaceous matter (Zone 6 in the previous sections). A flake had developed close to the boundary between Zones 3 and 4, but the detached piece containing Zone 3 had been preserved. Two samples were taken from Zone 3, one towards the front and the other adjacent to the flake, one sample from Zone 4, one from the grey-white zone adjacent to Zone 4, and one from the back of the brick. In breaking up the brick to take samples it was noted that it fractured readily along a plane situated approximately at the junction between Zone 4 and the white zone. Analyses of the various zones were as follows :

Zone :	3A.	3B.	4.	5.	6.
SiO_2 , %	5.53	5.21	3.96	2.44	3.00
TiO_2 , %	0.21	0.14	0.26	0.20	Tr.
Al_2O_3 , %	5.25	4.36	4.51	1.42	2.32
Fe_2O_3 (total iron), %	2.98	1.35	1.49	2.63	1.94
MnO, %	0.04	Tr.	...	...	...
CaO, %	38.50	56.30	53.42	53.90	53.90
MgO, %	45.80	32.22	37.00	39.42	38.60

Values corrected for loss on ignition.

The main points to note in connection with these analyses are as follows : The SiO_2 and iron oxide drop progressively from the front portion of Zone 3 onwards. The Al_2O_3 remains high till beyond Zone 4, when it drops abruptly, thus confirming the indication previously obtained that Al_2O_3 has greater penetrating power than iron oxide, and probably accounting for the fused appearance of Zone 4. At the same time (on the basis of the ratio of CaO to MgO and subject to the measure of uncertainty previously discussed) there has apparently been a large migration of CaO into Zone 3B and a much smaller one into Zone 4. In this case Zone 3A has become depleted in CaO. As in the previous samples, the MgO increases towards the hot face, but there is the same uncertainty as to whether this is due to change in concentration only, or to migration, or

both. Zone 6 can probably be taken as reasonably representative of the original brick. On the whole these relationships confirm and amplify the observations made on the previous samples, minor differences arising possibly from slight differences in conditions.

The laws governing the penetration and zoning of fluxes in refractories under the influence of a temperature gradient are as yet largely unknown. It is fairly certain, however, that such penetration must be considered, not in terms merely of the melting points of possible compounds, but rather in terms of those of possible eutectics. In doing so the chief handicap is generally lack of data regarding melting relationships in the complete systems involved. Nevertheless, some explanation of the fact that Al_2O_3 has greater penetrative power with regard to dolomite than has iron oxide is forthcoming from a study of existing data on the systems $\text{CaO}-2\text{CaO}.\text{SiO}_2-5\text{CaO}.3\text{Al}_2\text{O}_3-4\text{CaO}.\text{Al}_2\text{O}_3.\text{Fe}_2\text{O}_3$ (Lea and Parker³), $\text{CaO}-\text{MgO}-2\text{CaO}.\text{SiO}_2-5\text{CaO}.3\text{Al}_2\text{O}_3$ (McMurdie and Insley⁴), and $\text{CaO}-\text{Fe}_2\text{O}_3-\text{Al}_2\text{O}_3$ (Hansen, Brownmiller, and Bogue⁵). Examination of the diagram of the latter workers (*see* their original paper or Fig. 10*a* of the paper by White⁶) shows that the temperature along the boundary of the primary CaO field drops progressively as the ratio of Al_2O_3 to Fe_2O_3 increases, reaching a minimum close to the $\text{CaO}-\text{Al}_2\text{O}_3$ boundary of the system. In other words, the lowest-melting liquids that can occur in the presence of undissolved CaO are high in Al_2O_3 and low in Fe_2O_3 , and on solidification will give CaO , brownmillerite, and tricalcium aluminate such as was, in fact, indicated for Zone 3*B* in Table VII. Such liquids can, of course, penetrate farther into the brick than can liquids higher in iron oxide.

Specific gravities, bulk densities, and true porosities were also determined on samples from these zones with the following results :

Zone :	3 <i>A</i> .	3 <i>B</i> .	4.	5.	6.
Sp. gr.	3.448	3.327	3.327	3.323	3.313
Bulk density	2.938	2.863	2.791	2.591	2.733
True porosity	15.0	14.0	16.2	22.2	17.6

As might have been expected, the specific gravities and bulk densities are highest towards the hot end of the brick, where flux penetration and, in particular, iron oxide penetration is greatest. Correspondingly, the porosities are lowest in this region. It is significant that the highest porosity occurs in Zone 5, which is generally somewhat weaker and more readily fractured than the rest of the brick. All the porosities tend to be low, however, relative to what would be the value for the original brick (*see* Table V.), but this may have been due to hydration before receipt, as all the samples analysed showed appreciable loss on ignition.

Sulphur Pick-up by S.S.D. Bricks in Basic Electric Furnaces.

The figures in Table VI. show that dolomite bricks may pick up appreciable amounts of sulphur in the basic electric furnace, and further that there is a tendency for this sulphur to concentrate away from the hot face of the bricks. At the time of writing the analytical data on this point are as yet incomplete. It has, however, been found possible to demonstrate the presence of sulphur as sulphide in used side-wall bricks by the ordinary method of sulphur printing on bromide paper previously steeped in dilute sulphuric acid, sectioned bricks being used for the purpose.* The prints obtained show that the sulphide reaches a maximum concentration in Zones 4 and 5, being relatively low in the dark zone at the back of the brick. Examples of this are shown in Figs. 6 and 7. It seems likely,

* This method was suggested by Mr. B. Newbould of Messrs. Thos. Firth and John Brown, Ltd.

therefore, that the relative weakness of Zone 5 may be associated with the pick-up of sulphur, which, owing to the relatively low specific gravity of calcium sulphide (2.815) may cause sufficient expansion to loosen the texture to some degree. In Zone 4 this effect is possibly counteracted by the fact that vitrification due to flux penetration has occurred. In Fig 7. the unstained area in Zone 5 was due to the fact that hydration had started to occur in the sample owing to keeping, and caused this zone to crumble on cutting. In general, Zone 5 hydrates early in used bricks.

A somewhat surprising result was obtained when attempts were made to obtain sulphur prints from samples of S.S.D. bricks from the dolomite roof mentioned earlier, in that no evidence of sulphide sulphur could be obtained. The full explanation of this absence of sulphide sulphur from the roof-bricks is not yet apparent.

ATMOSPHERIC CONDITIONS IN THE ELECTRIC FURNACE AND THE MECHANISM OF FLUX TRANSFER.

The data of Tables VI. and VII. indicate the pronounced effect of furnace atmosphere on the refractories. During melting and the subsequent oxidizing period it is clear that oxidizing conditions must on the whole prevail, though the exact condition will vary somewhat as the doors are opened and closed and as the boil develops and subsides. Combustion of the incandescent electrodes will, of course, tend to use up oxygen, but as against this there is a distinct chimney effect in the furnace, and it is rarely if ever that the doors are closed tightly enough to prevent this. During the refining period, on the other hand, every effort is made to keep the doors closed as tightly as possible and to reduce to a minimum the periods when they are open. Further, the copious evolution of fume at this period generally seals up the electrode ports effectively, thus destroying the chimney effect to a large extent. To obtain some idea of the nature of the atmosphere to which the refractory may be subjected at this period, gas samples were drawn by means of a fused-silica tube from an 8-ton furnace during the refining period of two different heats, at a time when the doors were closed and a normal, highly-reducing condition was being maintained. The analyses of the three most highly reducing samples obtained were :

	Sample 1 (Heat A).	Sample 2 (Heat B).	Sample 3 (Heat B).
CO ₂ , %	3.4	2.6	0.1
O ₂ , %	1.3	0.7	0.7
CO, %	57.8	56.2	87.2
N ₂ (by difference), %	36.3	40.5	12.0

None of these samples can be considered as being at equilibrium, as the oxygen content is much too high, possibly owing to the presence of air currents infiltrating through the doors. After complete combustion had occurred, however, and equilibrium had been attained, all would be highly reducing towards iron oxides, *e.g.*, Sample 3 at 1600° C. would be in equilibrium with an oxide approaching FeO in composition. This, of course, is confirmed by the data of Tables VI. and VII. Somewhat unexpected features of these samples are the high CO and low nitrogen contents, which suggest that gas evolution was occurring in the furnace, that nitrogen was being consumed, or that stratification of the gases had occurred.

While the gas samples were being taken, fume was being evolved copiously and a sample of this was obtained from each heat. A qualitative analysis of each of these samples gave similar results, the main "fixed" constituents being MgO, CaO, and iron oxide, with a somewhat smaller amount of SiO₂. A semi-quantitative estimate of these was made in the case of the sample from Heat B and indicated approximately 20-25% of

MgO, 20–25% of CaO, about 20% of Fe_2O_3 , and about 10% of SiO_2 . On treating the samples with water a faint smell of acetylene could be detected, but no visible effervescence occurred, which apparently indicated the presence of traces of a carbide decomposable by water. On treatment with hot hydrochloric acid, however, a distinct effervescence occurred and the smell of acetylene and H_2S could be detected. At the same time a considerable separation of carbon occurred. A sample of the gases obtained by acid treatment of the Heat *B* fume was collected and subjected to further tests. It was found to consist of H_2S , hydrogen, and a hydrocarbon, indicating the presence of a sulphide, and a water-resistant carbide (possibly iron carbide). A certain proportion of uncombined metal may also have been present. Tests for nitrides gave a negative result. A rough estimate of the amount of H_2S evolved indicated that there was probably 2–3% of sulphur as sulphide in the original fume, but this is very approximate.

It is of interest to compare these figures with the analyses recently given by Mueller ⁷ of arc-furnace melting-shop fume, two of which are :

	Sample 1.	Sample 2.
Fe_2O_3 , %	20	19
Cr_2O_3 , %	1.5	1
MnO , %	1.5	4
SiO_2 , %	22	14
Al_2O_3 , %	1	2
CaO , %	21	22
MgO , %	30	38
Loss on ignition, %	5	0

There is obviously a close correspondence between these figures and the present results.

It was noticed in taking the present samples of fume that the particles readily adhered to surfaces with which they came in contact, and it is to be expected that appreciable deposition of fume must occur on the somewhat sticky surface of the refractory in the furnace. From the amount of the samples withdrawn from the furnace in a few minutes by a slow gas stream, it is evident that such deposition must reach appreciable proportions. In this connection it is clear, from the chemical nature of the fume, that basic refractories will be much less affected by it than will acid refractories, towards which it will act as a powerful flux.

The mechanism of such fume formation is of considerable interest. Two distinct types of fume are apparently evolved during the basic electric-furnace process. That evolved during the oxidizing period is slight in amount and of a brownish colour and apparently contains a considerable proportion of iron oxide. This is to be expected since iron oxide (as well as metallic iron) is known to be appreciably volatile at steel-making temperatures and will be decidedly so at arc temperatures. Cr_2O_3 , manganese oxides, and fluorides are also likely to be found in the fume at this time. The fume evolved during the reducing period is of a different character, being much denser and of a white to grey colour. It appears that two different mechanisms are involved in its formation, the first being ordinary volatilization, and the second, which appears to be at least partly responsible for the increased fume evolution during refining, depending on the formation of volatile substances by reducing reactions which only become thermodynamically possible in the immediate vicinity of the arcs. The presence of such large amounts of MgO in the fume is probably the result of such a reaction, for though MgO is a highly stable oxide, the fact that magnesium has an exceedingly high vapour pressure makes its reduction by carbon, silicon, and other strong reducers possible at high temperatures under suitable conditions. The indications are that at the temperature of

the arcs this reaction proceeds fairly readily during the reducing period. The magnesium vapour so formed immediately re-oxidizes on escaping from the zone of the arcs, with formation of a fume. Silica may also act in a similar way, as at high temperatures it is known to be readily reducible with formation of a volatile sub-oxide.

Fume formation is, of course, by no means the only way in which fluxes, &c., find their way to the refractory. True vapours and gases will also no doubt play a considerable part, as, for instance, in the transfer of sulphur and silicon as SiF_4 . In addition, splashing during feeding and during the boil and the presence of dust in the materials fed all have an important bearing on refractory life. For example, cases are known where the use of limestone instead of a rather dusty lime has increased the life of silica roofs by as much as 50%. Nevertheless, in spite of all precautions, flux will undoubtedly always find its way to the refractory, and flux resistance will remain one of the primary requirements of the latter. In this respect basic refractories possess undoubted advantages over their acid counterparts.

ACKNOWLEDGMENTS.

The authors particularly wish to thank Mr. E. Dawtry and Mr. B. Newbould, of Messrs. Thos. Firth and John Brown, Ltd., for all the help they have given in preparing this paper. Mr. Dawtry was one of the earliest users of the semi-stable dolomite brick and its development is due in no small measure to his interest.

The authors also wish to express their indebtedness and thanks to the following firms, and to certain others who have preferred to remain anonymous, for having kindly and unreservedly provided service data relating to the performance of refractories in their basic electric furnaces: Clyde Alloy Steel Co., Ltd.; Ministry of Supply Factory, Linwood; Colvilles, Ltd., Dalzell Works; Samuel Osborn & Co., Ltd.; David Brown and Sons Ltd.; Head, Wrightson & Co., Ltd.; Brown, Bayley's Steel Works, Ltd.; Davy and United Roll Foundry, Ltd.

REFERENCES.

1. BRADLEY and JAY : *Proceedings of the Physical Society*, 1932, vol. 44, p. 563.
2. RAIT and GOLDSCHMIDT : *Journal of The Iron and Steel Institute*, 1945, No. I., 391 p.
3. LEA and PARKER : *Philosophical Transactions of the Royal Society*, 1934, vol. 234, p. 1.
4. McMURDIE and INSLEY : *Journal of Research of the [U.S.] National Bureau of Standards*, 1936, vol. 16, p. 467.
5. HANSEN, BROWNMILLER, and BOGUE : *Journal of the American Chemical Society*, 1928, vol. 50, p. 396.
6. WHITE : *Journal of The Iron and Steel Institute*, 1943, No. II., p. 519 p.
7. MUELLER : *Stahl und Eisen*, 1941, vol. 61, p. 685.

DISCUSSION.

Dr. J. H. WHITELEY (Consett Iron Co., Ltd., Consett, Co. Durham) : This interesting paper reports progress in the manufacture of dolomite bricks and I found it very readable. Towards the end it gets rather sticky perhaps, but that is excusable, since I think it is true to say that as our knowledge advances our ignorance often increases. Apparently the authors have two objects in view in this investigation, *viz.*, (1) to improve the durability of dolomite bricks, and (2) to produce a brick that will enable steel to be made at considerably higher temperatures. Now with regard to the latter object I am not at all sure that it would be altogether an advantage to make steel at temperatures much exceeding those at present available, at any rate in the open-hearth furnace. My experience

indicates that for the best quality of steel there is an optimum temperature of working which is not far below that which a good silica brick will just stand. No doubt if higher temperatures could be used the melting and refining would be quicker, but the bath would then need to be cooled considerably before tapping, and, as that is a lengthy process in a large furnace, there might not be much overall gain in time. Moreover, it is probable that, among other things, hydrogen absorption, which is stated to increase with temperature, might cause serious trouble. Thus, I incline to the view that silica bricks in an open-hearth furnace act as a safeguard for quality, since they impose an upper limit to the temperature that can be employed.

The authors find that the sulphur content of a used S.S.D. brick increases steadily from the working face inwards as far as Zone 5, and I would observe that a similar increase was reported a few years ago in a paper on monolithic linings. In the discussion which then took place I suggested that this sulphur penetration might be due to the presence at the surface of the iron oxide-sulphide system, the eutectic of which melts at about 900°C. , and is a very penetrating fluid. Deterioration of the hearth could thus result, and it may be that this liquid is a contributory cause of flaking in dolomite bricks. Of course, the presence of sulphur as FeS needs to be established before this explanation can be accepted as a possibility. The authors consider that in Zone 5 the sulphur exists as calcium sulphide but it seems highly probable that in the zones nearer the working face FeS may occur, since Zones 1 and 2 contain no free CaO, and in Zones 3 and 4 that compound may be protected by silicates, &c. That at least part of the sulphur is present as a sulphide is clearly indicated by the sulphur prints, but I would point out that failure to obtain a print does not necessarily mean the absence of sulphide. In sulphur-printing steel, I have occasionally come across samples from which no print could be obtained from certain areas and yet when such parts were examined under the microscope many sulphide inclusions were to be seen in them. The failure to give a print seems to be connected in some way with the presence of oxygen (FeO, &c.) and I think it quite likely the authors will eventually find that the roof bricks actually contain some sulphide even though they do not give a sulphur print.

Lastly, I would refer to the analyses of the furnace atmosphere recorded in the paper. They show a deficiency in nitrogen which is very remarkable. The authors attribute it to either absorption or stratification in the furnace. Absorption, however, seems to be ruled out, for the nitrogen content of electric steels seldom exceeds 0.01%, and it is not present in any appreciable amount in the slag. Moreover, the authors failed to find any in either the bricks or the fumes. Apparently, therefore, stratification is the cause, proof of which ought to be obtainable without much difficulty by taking samples simultaneously at different heights in the furnace.

MR. F. T. BAGNALL (Messrs. Samuel Fox & Co., Ltd., Stocksbridge, near Sheffield): This paper is very interesting from the point of view of electric-arc furnace practice. My remarks are made from the view-point of an electric-steel maker, and not from an academic point of view. The authors have emphasized, particularly, the effect on refractories of the modern type of furnace with a removable roof for basket charging and of the high voltages which are used in the electric-arc furnace to-day. We do appreciate that the types of lining which we use to-day, the chrome-magnesite brick and the dolomite brick, as compared with the practice many years ago, when we simply had the silica brick for the side wall, have made it possible to secure a reasonable furnace life with the high

voltages which we are using to-day. We realize that the removable roof should, in theory, have a bad effect on refractories in general; but if we look through the figures which are given in this paper for different furnaces, some machine-charged, some hand-charged, and some basket-charged, we find that the open-roof furnace gives as good a life of side wall as the fixed-roof. Looking through the figures generally, we can say that the open-roof type gives a better life of side wall on the facts as given, though I agree that in theory it should be worse.

With regard to roof life—roofs are not mentioned in the paper, except for the basic roofs—we have had instances during the last year of five roofs a year on a 10-ton open basket-charged furnace where the scrap is not very good from the steelmaking point of view and where that roof has probably to be removed once or twice in the middle of the breaking-down process. The importance of the opening and closing of the roof is emphasized in the paper from the point of view of the lining life, but on figures like that we can say that there is not the bad effect on refractories which might be expected. That was an average of over 200 casts to a roof. With regard to larger furnaces, I had to run a battery of 20-ton furnaces in the North, and on the five furnaces we had an average side-wall life of 160 casts, which would mean nine or ten weeks.

For side-wall life, a great deal depends, in my opinion, on the design of the furnace and the thickness of side wall that can be put in, and also on the margin of safety that the control of the furnace will stand. There are some firms which prefer not to risk using a side wall again after a week-end; they prefer, if there is any doubt at all, to knock the lining out on the Sunday rather than feel that they might have a breakdown on the Wednesday. Any figures relating to side walls, therefore, depend to a great extent on the view taken of what should be done in that respect. At present, on 10-ton furnaces we make a point of knocking our lining out every month, or at the most every five weeks, whether it seems to need it or not. More detail is required about these figures, therefore, than it is possible to give in the paper.

Many people, rather than use dolomite bricks, prefer to ram with dolomite to the top, but I feel that the dolomite brick is better, because it is much easier and quicker to brick a wall rather than to ram a wall, and if, having rammed a bottom, it is possible to slip a few bricks in crowns and squares it is easier, cleaner and better, in that form, from the point of view of output than ramming to the top.

Mr. A. G. E. ROBIETTE (Messrs. John Miles & Partners (London), Ltd.): Mr. Bagnall has raised the point that when you have a top-charging furnace you often find that you get a longer, instead of a shorter, roof and side-wall life. This, I think, is quite understandable even in spite of the long arcs on modern fast melting furnaces. The reason is that with a top-charging furnace you can fill the body until the charge is flush with the top of the side walls. The arcs soon pierce the charge and for most of the melting-down period the side walls are masked from direct radiation from the arc. In a door-charged furnace the upper side walls are never thus shielded. I think that this is a vital factor affecting roof and side-wall life.

I should like to ask the authors a question in regard to dry-rammed dolomite side walls. They refer in the paper to some furnaces having Crespi-type bottoms but they do not compare any furnaces having Crespi-type side walls. I have seen furnaces with such linings which have given up to 350 heats per side wall with only minor patching. That was on small foundry furnaces where normally much hotter steel is required than in ingot shops. I think, therefore, that a comparison with a monolithic dolomite side wall would be of interest.

Mr. W. L. KERLIE (Messrs. Stewarts and Lloyds, Ltd., Corby): I think this paper is an excellent contribution to the work on electric-furnace refractories generally, apart from its reference to dolomite. It would appear that the performance of the S.S.D. brick is equally as good as that of rammed dolomite, and from a production standpoint there is no doubt that the facility with which the S.S.D. brick can be installed is a tremendous asset. In general, the mode of failure is somewhat similar to that of well-rammed dolomite linings, and this is not surprising in view of the fact that the materials used—calcined dolomite and tar—are essentially the same, so that one would expect the results to be similar.

I am glad to see that the authors have paid a great deal of attention to the question of flaking; they have shown, and I think rightly, that the penetration of fluxes has a great deal to do with this.

I should like to mention one point on which the authors may care to express an opinion. If a piece of tarred dolomite is heated, there is a gradual expansion up to a temperature in the region of $1000^{\circ}\text{C}.$, and from 1000° to $1300^{\circ}\text{C}.$ the curve flattens out, while from $1300^{\circ}\text{C}.$ to a little above $1400^{\circ}\text{C}.$ there is a very marked and rapid contraction. One can imagine that in an electric furnace the hot face has reached a temperature above $1300^{\circ}\text{C}.$, which extends to a depth in the region of 2 in., so that the front face will be in a shrunken condition, whereas beyond a 2-in. depth the dolomite will be in its most expanded state. It seems more than likely, therefore, that the front sintered face will shear off, not only owing to the effect of the fluxes but also because of the shrinkage which takes place. Whether this is the case in actual practice or not still remains to be seen, but it would be interesting to have the authors' opinion on that point.

I think the authors could have emphasized even more the failures of dolomite linings due to channelling, the effect of silica drip and small pieces of silica which have spalled from the roof and dropped on to the side-wall lining. I feel that this is probably the primary cause of failure of side-wall linings. It might be interesting to be given some idea of the condition of the side-wall lining after the removal of the S.S.D. roof which gave a life of 57 heats. Was there any evidence of channelling in that side-wall lining, which was reported as being still in very good condition?

The last point which I wish to raise is the effect of the rate of heating. Can any indication be given of whether the rate of heating of the furnace in the first instance is likely to have any effect on the flaking, as with a fast rate of heating the front or hot face of the dolomite brick may frit very thoroughly and prevent the penetration of fluxes?

CORRESPONDENCE.

Dr. A. H. B. CROSS (Brown-Firth Research Laboratories, Sheffield) wrote: The authors are to be warmly congratulated on their presentation of a most valuable study of a class of basic refractory which has done yeoman service during the past six years of war in many electric-steel plants. Their work has advanced our knowledge of the causes of the observed behaviour of semi-stabilized dolomite-brick linings in electric-arc furnaces to a notable degree, and the explanations they offer to account for their observations merit careful study and thought by all makers and users of such materials.

The enthusiasm of Mr. Dawtry and his senior staff for the semi-stable dolomite-brick lining has persisted through all trials and tribulations for a number of years and the authors' acknowledgment of this unity of purpose is both timely and appropriate. When war conditions severely curtailed the magnesite imports to this country, our works had already established

over some years a furnace lining and operational technique which took full advantage of the valuable slag-resisting properties of semi-stable dolomite bricks and was dependent, in some measure, on the relatively satisfactory thermal-shock resistance of this material.

Some years before the war, semi-stable dolomite bricks differed from those employed to-day in that partial stabilization was effected by clay or felspar additions, and a difficult and costly two-stage firing was involved which, with the means available at the time, resulted in a somewhat variable product, the best of which, however, was very good as regards furnace performance and had fairly satisfactory storage life (up to 2 months). The present-day bricks are more comparable with other bricks as regards uniformity and may be stored, under reasonable works conditions of temperature and humidity, up to 4 months or more, as the authors indicate.

One valuable result of the earlier experience and standardization of the semi-stable brick for furnace linings was that cessation of magnesite supplies called for no significant change in materials of construction or method of operation of the plant. The details of our lining and warming-up practice were made available to the industry *via* the Chrome Ore, Magnesite and Wolfram Control in 1941 when the present type of brick had been successfully used for some time.

The technical evidence given in the paper with regard to the chemical, mineralogical, and physical characteristics of the various zones developed in service and the theories developed from it accord well with the observed performance of the bricks. A difficulty in sampling, not encountered in the case of silica furnace linings (*e.g.*, open-hearth), is caused by the "dusting" of Zone 2 or the flaking between Zones 3 and 4 which compels collection of the "hot-face" samples at high temperature. On the authors' assumption that Zone 6 may be taken as reasonably representative of the original brick, and utilizing the analytical data given in Table VI. and on p. 368 P, it may be possible to assess the gain or loss of various oxides by regarding the whole brick as a single entity and weighting the analytical data according to the dimensions of the separate zones. The figures below have been calculated from analyses of samples taken "after reducing period" to give the average composition of the first five zones for comparison with that of Zone 6.

	Weighted Average of Zones 1-5, %	Zone 6 (unaltered brick) %
SiO ₂	6.0	3.0
Al ₂ O ₃	3.2	2.3
Total Fe as Fe ₂ O ₃	6.7	1.9
TiO ₂	0.2	Trace
CaO	45.2	53.9
MgO	38.2	38.6
Totals	99.5	99.7

These values suggest that the net effect of service in the arc-furnace lining, on composition, amounts to the following gains (+) and losses (-):

	Gains (+), %.	Losses (-), %.
SiO ₂	3.0	...
Al ₂ O ₃	0.9	...
Total Fe as Fe ₂ O ₃	4.8	...
TiO ₂	0.2	...
CaO . . . . .	...	8.7
MgO . . . . .	...	0.4
Totals	8.9	9.1

Insufficient data are given to enable the Cr_2O_3 , MnO , and SO_3 to be included, but there seems little reason to doubt that each of these would appear on the "gains" side.

The loss of lime, by fluxing and draining away at the hot face, is clearly indicated and is not opposed to the authors' demonstration, on p. 365 P, of the migration of lime away from the hot face to cooler regions of the brick (Zone 3B).

The gain of aluminina appears to be definite and is similar in amount and depth of penetration to that which has been observed in silica bricks in the block face of the acid open-hearth furnace. The pick-up of iron oxide is notably lower than that found in the back wall, block face, and air- and gas-port brickwork of the acid open-hearth furnace. It is considered that the alternating atmosphere conditions of the arc furnace and drainage account for this difference as the concentrations of iron oxides in Zone 1 are much higher than those normally found in open-hearth silica bricks with the exception of the gas port. Similar amounts of both ferrous and ferric oxides have, however, been observed in gas-port silica bricks after similar periods of service.

The apparent absence of sulphide sulphur from dolomite roof bricks is surprising, and will, no doubt, be confirmed in further tests by the sulphur-printing method, and by comparison with analytical determinations of total sulphur in the various zones. The point is clearly an important one if the authors' views regarding the weakness of Zone 5 are accepted and the stability of a dolomite roof is considered. The initial trial of such a roof is not without promise and solution of the existing problems will be of considerable advantage to the electric-steel maker.

Dr. G. R. RIGBY (British Refractories Research Association, Stoke-on-Trent) wrote: The authors of the paper are to be congratulated on giving a detailed and comprehensive description of the properties and performance of a very promising refractory material for the linings of electric-arc furnaces, *viz.*, the semi-stabilized dolomite brick.

The reactions involved in the slagging of the semi-stabilized dolomite brick are of particular interest in that they bear certain similarities to the slagging of a magnesite brick obtained from the lining of a metal mixer which was the subject of an investigation at the Mellor Laboratories some years ago. The working face of this magnesite brick contained a high percentage of iron oxide, and free magnesia was absent. This is similar to Zone 1 of the used semi-stabilized dolomite brick except that with this refractory free lime was absent. Immediately behind the iron-oxide zone of the magnesite brick was a thin layer consisting almost entirely of magnesium orthosilicate-forsterite, which corresponds to the calcium-orthosilicate layer which forms Zone 2 of the semi-stabilized brick.

In the case of the magnesite brick, the hot face absorbed both iron oxide and silica, which initially combined with the free magnesia to give magnesioferrite and forsterite. As soon as the last traces of free magnesia disappeared further silica pick-up resulted in the formation of the low-melting-point metasilicates of the enstatite type, which, being liquid, withdrew into the brick proper where they encountered free magnesia and became concentrated as a forsterite layer behind the face, the forsterite layer acting as a division between the face of the brick, where no free magnesia was present, and the remainder of the brick which contained free magnesia.

It seems possible that an explanation on similar lines might be applied to account for the zones of the semi-stabilized brick. Silica and iron-oxide pick-up would preferentially combine with the free lime at the face to give initially calcium ferrites and calcium orthosilicate. As soon as

all the free lime disappeared at the face further pick-up of silica would either combine with the orthosilicates to give metasilicates or with the free magnesia. In this connection it is interesting to observe the detection of merwinite in the case of the brick sample taken after the reducing period. It would appear, however, that pyroxenes of the lime/ferrous-oxide/silica series might form preferentially to merwinite or monticellite. These metasilicates, being liquid, would then concentrate behind the working face and recombine with free lime to form the dicalcium silicate of Zone 2. The formation of liquid metasilicates would be continuous, and at any period there would be very little present as they would be continually recombining behind the working face to give calcium orthosilicate. This would account for the absence of metasilicates in the phases identified by X-ray analysis, but it is possible that petrological examinations carried out on thin sections might reveal isolated areas of metasilicates in Zone 1.

The corresponding Zones 3A and 3B of the semi-stabilized dolomite brick are absent in the magnesite brick, and it would certainly appear that alumina is responsible for the fluxing in this zone. Recent investigations at the Mellor Laboratories have shown that none of the three oxides of iron reacts with dicalcium silicate, but phase-rule data would indicate that alumina, on the other hand, would react with dicalcium silicate, giving low-temperature eutectics owing to the formation of ternary compounds of the gehlenite type which would concentrate at some distance behind the orthosilicate zone.

The possibility of solid solutions occurring between ferrous oxide and lime is particularly interesting in view of earlier work by Hay and White which indicates that ferrous oxide decomposes in the presence of lime to give dicalcium ferrite and free iron. All investigations at the Mellor Laboratories have confirmed those findings of Hay and White, and it would be of interest therefore to know if the authors of the present paper hold the view that under certain conditions ferrous oxide is stable in the presence of lime.

F/O N. F. DUFTY (Armaments Design Department, Fort Halstead, Kent) wrote: The authors are to be congratulated on their excellent paper, particularly as it is the first time the subject has been tackled in a thorough, comprehensive, and practical manner. It is to be hoped that they will continue the good work that they have begun so well.

On p. 367 P of the paper, the opinions are expressed of both Jay and the authors, that ferrous oxide can be present in solid solution in the lime. During the petrographic examination of undissolved lime in electric-furnace slags that were highly oxidizing and also very basic, the writer came to the conclusion that lime definitely could take some ferrous oxide into solution. Unfortunately, no X-ray facilities were available to enable this to be confirmed or refuted. The authors may find this to be some little additional evidence.

A second point arises in connection with the constitution of electric-furnace fume. The exact time of taking the fume samples is not stated in the text. It is known that the fluorine content of the slag drops during the refining period and that this fall cannot be accounted for by dilution alone. In the writer's opinion, the fume at the beginning of the refining period, *i.e.*, when the slag-mix has just been thrown on and is being fluxed, is, visually at any rate, different from that produced later on during the refining period. It is suggested that fume and gas samples are taken immediately after the slag-mix has been added. In this way some light may be thrown on the constitution of any fluorine compounds present and their effect, if any, on the life of the refractories. A straight slag-mix of lime and calcium fluoride could be used to eliminate the possibility of unknown variables

due to impurities in the fluorspar. The writer has worked with such a slag-mix quite successfully when low sulphur contents have been desired and the local fluorspar has been high in sulphates. Experiments with and without additions of fine carbon could be tried to see if organic compounds such as carbon tetrafluoride are produced; and a similar series during the oxidizing phase, without, of course, the addition of carbon, might yield additional information.

AUTHORS' REPLY.

The AUTHORS wrote in reply: We should first of all like to thank all those who have taken part in the discussion for their appreciative remarks and their exceedingly helpful and constructive comments.

In opening the discussion Dr. Whiteley referred to the paper as being rather "sticky" towards the end. This is presumably connected with what was said in introducing it, namely, that a good deal of the work described in the latter part of the paper was of an exploratory nature, and does not allow us to reach final conclusions, though it does, we think, draw attention to certain important aspects of the fluxing of arc-furnace refractories which will be well worth while following up.

It is perhaps not quite correct to say that one of our aims was to produce a brick which would enable steel to be made at considerably higher temperatures. The main object in producing the 100% dolomite brick was to produce, from materials available in Britain, a brick which would be at least as durable in the furnace as alternative materials of comparable cost. The possibility that higher temperatures might be attainable emerged incidentally from observations made during the roof trial. We do not feel competent to express an opinion at the present stage on the optimum temperature of steelmaking, but it is a fact that one of the main arguments advanced before the war in favour of the all-basic open-hearth furnace was that it would be possible to run it at higher temperatures, with a consequent speeding-up of the steelmaking reactions. Whether or not this would enable better steel to be made is another matter. For one thing, as is well known, the efficiency of de-oxidation falls off as the temperature rises, which would mean higher oxygen contents in the steel in equilibrium with a given metalloid content (with the possible exception of carbon). The increased solubility of hydrogen is another factor which Dr. Whiteley has mentioned. On the other hand, higher temperatures would, in many cases, help considerably in the matter of forming and controlling the slag, and would lead to the more rapid elimination of inclusions, particularly where difficult slags of the type met with in making certain classes of alloy steel are encountered. It is certainly the case that the users of the furnace on which the roof trial was carried out expressed the opinion that the ability to reach higher temperatures would be advantageous to them. Ultimately, however, the question of a possible optimum temperature can only be settled if and when higher temperatures do become attainable and the necessary statistics become available.

Regarding the mechanism of sulphur pick-up by the bricks, we do not make any claim to have identified calcium sulphide, but we rather favoured the idea because of the whiteness of the high-sulphide zone indicated by the sulphur prints. We do not rule out the possibility of iron sulphide playing a part, however, though the fact that this white zone occurs beyond the limit of flux penetration and is low in iron rather militates against the idea that sulphur enters it as a fluid iron-sulphide/iron-oxide eutectic. Another point is that the white zone tends to be somewhat friable, which seems to be associated with a slight tendency to

expand. We do not think that the penetration of a liquid phase *per se* could account for this effect, though the formation of a solid phase of high specific volume could. Calcium sulphide has a high specific volume relative to that of lime. Towards the hot face of the brick iron sulphide is certainly a possibility, though it was in this zone that no sulphide sulphur could be detected by the sulphur-print method. In this connection we are indebted to Dr. Whiteley for drawing our attention to the possible inhibiting effect of iron oxide on the sulphur-print reaction. We rather overlooked this possibility in considering our sulphur prints, but it is quite feasible that the presence of a reducible oxide in sufficient amount could interfere with the formation of the hydrogen sulphide necessary to produce a stain. Evidence on this point is available in that the presence of iron oxides can lead to low results during the determination of sulphur by the evolution method. Actually, since the paper was written we have obtained some additional information on this point by determining the sulphur contents in the zones of a number of used bricks by the gravimetric method, and the evidence is that appreciable sulphur can occur in the region of the hot zone as well as further back in the brick. Since the temperature here would appear to be too high for the existence of sulphate (calcium sulphate dissociates at about 1250° C. in an atmosphere free from the oxides of sulphur), it seems likely that some effect of the kind postulated by Dr. Whiteley does occur.

With regard to the figures for the gas analyses, it is, as Dr. Whiteley points out, difficult to account for the loss of nitrogen as due to absorption. There remain, therefore, the alternative suggestion, stratification, and one other possibility to which we have alluded, namely, that carbon monoxide is being generated in the furnace without the aid of atmospheric oxygen, *e.g.*, by the reduction of oxides in the arcs. The very obvious pressure generated in a furnace running with the doors closed, during the reducing period particularly, suggests that something of the sort occurs.

In reply to Mr. Bagnall, we would assure him that his apology for speaking from the "steelmaking" rather than from the "academic" point of view is unnecessary. We welcome his contribution, particularly as we regard the paper as primarily of a practical nature. The "academic" matter in the second half of the paper arose, as such matter usually does, simply in the search for ultimate causes. We are indebted to him for his comments concerning the effect of removable roofs on lining life, and do not think that his remarks are necessarily at variance with the views expressed in the paper. We still believe that roof removal *per se* is likely to increase the stresses on the refractories owing to the rapid chilling that occurs. At the same time we realise that refractory life is the integrated effect of a great many factors, and in this connection we believe that Mr. Robiette, in drawing attention to the additional screening of the arcs resulting from this method of charging, has indicated at least one reason why roof-charged furnaces are not in actual fact inferior to door-charged furnaces in the matter of refractory life. We have specifically drawn attention in the paper to the importance of screening the arcs as much as possible from the refractories during the initial stages of melting down.

The average life of 160 heats per side wall for five 20-ton furnaces quoted by Mr. Bagnall is undoubtedly a good one. It is suggested in the present paper that larger furnaces with walls further from the arcs have a better chance of giving long wall-life than smaller furnaces. At least we think so, and we believe that this has something to do with the rather phenomenal figures claimed for some American furnaces.

It is, of course, true that the figures for lining life given by different

users will be affected by the views of the operators concerned as to when the lining should come out. We are also familiar with the consideration which makes the operator put his furnace off at the week-end, even when a certain life remains in the lining, rather than risk a mid-week shut-down, and we have, in fact, referred to this in the paper. This practice does undoubtedly obscure the issue somewhat when performance figures are being compared.

In reply to Mr. Robiette, we have not, unfortunately, any direct information regarding the lives of dry-rammed side walls, though we understand that very good lives can be obtained. Our own experience is that, when it comes to the question of bricking or ramming, the ease and rapidity of installation of bricks weighs heavily with most operators. Also, to obtain the optimum life with a rammed lining close control over grading, mixing and installation is necessary. Any relaxation of that control generally leads to an immediate falling-off in life.

In reply to Mr. Kerlie, we agree that the mechanism of failure with a rammed lining should, from the chemical point of view, be similar to that occurring with bricks. Flaking appears definitely to be associated with the penetration of fluxes, and we are pleased to hear that Mr. Kerlie is in agreement with us on this point. It is quite distinct from ordinary thermal spalling, though the latter may play a part in accelerating the detachment of the flake. It might perhaps be included under the rather loosely defined term "structural spalling."

Mr. Kerlie's observations on the volume changes undergone by tarred dolomite on heating are naturally of great interest to us. We have not found any measurable swelling to take place when tar-dipped dolomite bricks are heated in laboratory furnaces, while the shrinkage during the ordinary after-contraction test is not usually large, being of the order of 0.2-0.5% linear with a well-fired brick. It must be remembered that such a brick has been previously fired to produce a ceramic bond and retains a high degree of rigidity up to at least 1000° C., by which time the tar should have been burned out. Again, during the initial firing the shrinkage should have been largely if not entirely removed. It might, however, be possible to produce bloating followed by aggravated shrinkage at higher temperatures if the rate of heating was too rapid to allow removal of the tar at low temperatures. We have not, however, found any indication of this. With regard to the possibility of shrinkage at the hot face causing or contributing to flaking, this is *a priori* an entirely reasonable hypothesis, and we ourselves did consider this possibility but have not obtained any indications that this was occurring. We have indicated in the paper that some shrinkage at the hot face may occur during the initial pick-up of fluxes. By the time that the hot face has become charged with fluxes, however, all evidence of any such shrinkage has disappeared, and it is at this stage rather than earlier that signs of flaking begin to appear.

We are in complete agreement with Mr. Kerlie with regard to the importance of silica drip as a cause of failure in side walls. It is undoubtedly one of the main causes of wear. Ample evidence of this was obtained from the examination of the side walls of the furnace fitted with the dolomite roof at the end of the campaign. On the average the wear that had taken place was of the order of an inch only, and, in answer to Mr. Kerlie's query, this wear was reasonably uniform (allowing for the effects of flaking) and channelling was entirely absent.

We have no information at present as to whether the initial rate of heating has any direct bearing on flaking, but, as far as our present knowledge goes, it would seem doubtful whether any attempt to frit or glaze the surface of a refractory such as dolomite would be very successful.

The ability to acquire a viscous glaze remains one of the outstanding advantages of siliceous refractories.

We thank Dr. Cross for his commentary concerning the development of the semi-stable dolomite brick lining and the part played by his firm in that development. His treatment of our analytical data is more rigorous than our own and is particularly instructive. We agree that the conclusion that drainage of lime occurs from the hot face in no way conflicts with the view that migration of lime into the brick also occurs. His demonstration that a small pick-up of Al_2O_3 does occur is particularly interesting. Though small in amount, the Al_2O_3 pick-up is likely to be of special significance, owing to the depth to which it penetrates. The analogy which he draws with the behaviour of Al_2O_3 in silica bricks is certainly instructive. In the latter case the migration of lime with the Al_2O_3 can readily be demonstrated, as CaO reaches a maximum in the same zone as does Al_2O_3 (and TiO_2), and the ultimate reason for the association of the two is apparently similar, since Al_2O_3 produces very low-melting eutectics in contact with primary, *i.e.*, solid, silica in the presence of CaO .

We have already dealt with the question of sulphur distribution in our reply to Dr. Whiteley's contribution. The question of sulphur in the roof still remains an open one, as, at the time of writing, we have had no further opportunity to examine roof samples. In view of the detection of sulphur chemically in zones in which sulphur-printing failed to show it, it is quite possible that sulphur does occur in roof bricks.

In reply to Dr. Rigby's contribution, we agree that there are similarities between the slagging reactions occurring in magnesite bricks exposed to iron-oxide slags and the slagging reactions described in the present instance. There is one major difference, however, namely, that in the case of dolomite lime is one of the main constituents of the system, whereas in the magnesite mixer blocks referred to by Dr. Rigby lime would be a minor constituent. For this reason we feel that the analogy should not be pushed too far, as the compositions encountered in the two cases fall in different phase regions of the oxide system concerned. The main difference is that when lime is low or absent appreciable amounts of low-melting liquids can only form at the hot face when slag pick-up has reached the stage at which metasilicates can form, which, at equilibrium, only occurs when the free MgO has all reacted. Hence it is to be expected that metasilicates will play a big part in the slagging of magnesite. When the lime is high, however, as in dolomite bricks, low-melting liquids can form as soon as flux deposits on the brick, owing to the formation of, for example, dicalcium ferrite or, in the presence of Al_2O_3 , brownmillerite or the low-melting eutectic referred to in the paper. These can form in direct contact with solid CaO and MgO , so that it is by no means certain that the unsaturated compounds (metasilicates, &c.) postulated by Dr. Rigby will ever appear. At any rate it is unnecessary to assume their formation to account for the penetration of fluxes into the brick. Incidentally, though it is convenient in the present state of our knowledge to describe the fluxing reactions in terms of the formation of fusible or infusible compounds, it is worth while remembering that in the ultimate analysis it is the presence of eutectics and of low-melting ranges of composition in general which determine the composition of the liquid migrating into the brick. One other point: We do not consider that gehlenite would occur in any of the zones of our samples, since, as is shown by the phase assemblages of Rait and Goldschmidt and ourselves (and it should be remembered that the phase assemblages are simply a statement of the phase relationships in a polydimensional phase diagram), gehlenite does not

appear as an equilibrium phase in the presence of uncombined MgO , which was present in all of our zones.

We are particularly interested to learn that work at the Mellor Laboratories has confirmed the finding of Hay and White that CaO and ferrous oxide react to give dicalcium ferrite and metallic iron. This confirmation was very desirable in view of the recent identification of two oxide phases in basic slags by Rait and Goldschmidt. This behaviour, however, is not incompatible with the existence of *partial* solid solubility between the two oxides, particularly when other divalent oxides are present. As one of us (J. W.) has dealt with this matter at some length during the discussion on the paper by Rait and Goldschmidt it is not proposed to discuss it in detail here, but if Dr. Rigby will consult the phase diagram of the system Ca-Fe-O proposed by Martin and Vogel either in the original paper * or as reproduced by White † he will see how partial solubility of CaO in FeO can occur even in the presence of a tie-line from Fe to $2\text{CaO.Fe}_2\text{O}_3$. Partial solubility of FeO in CaO can be accommodated similarly.

In reply to Mr. Dufty, we are decidedly interested to hear that he himself has obtained evidence for the solubility of FeO in CaO by microscopic examination. In view of Jay's earlier evidence on the same point, there can, we think, be little doubt that such solubility actually exists. We would also refer Mr. Dufty to our reply to Dr. Rigby regarding the so-called incompatibility of CaO and FeO .

Concerning the fume samples, these were taken approximately half an hour after the addition of the slag mix. We did not specifically look for fluorine in our samples, which were rather small, but Mr. Dufty's suggestion that fluorine should be looked for in the fume is a good one, as there has long been controversy as to the fate of the fluorine lost from the slag.

* *Archiv für das Eisenhüttenwesen*, 1934-35, vol. 8, p. 67.

† *Journal of The Iron and Steel Institute*, 1943, No. II., p. 636 P.

THE RELATION BETWEEN THE HYDROGEN CONTENT OF WELD METAL AND ITS OXYGEN CONTENT.*

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SYNOPSIS.

Considerable study of the welding of high-tensile steels in recent years has indicated that cracking may occur in the hardened zones of the base plate immediately adjacent to the weld. It has been shown by several investigators that certain types of weld metal, including highly oxidized ferritic types and austenitic weld metal, are largely immune from this cracking tendency. It has also been shown more recently that this may be related to the diffusible hydrogen content of the weld metal.

The main purpose of the investigation reported in this paper is to determine the relationship between the FeO content of weld metal and its total and diffusible hydrogen content.

It is shown experimentally that the total hydrogen content is slightly reduced, whilst the diffusible hydrogen content is considerably reduced, when the FeO content in the weld is increased. An attempt is made to explain these results theoretically on the basis of the data reported by Chipman (*Transactions of the American Institute of Mining and Metallurgical Engineers*, 1937, vol. 125, p. 331) for the system Fe-FeO-H₂-H₂O at temperatures above the melting point of iron, and from a discussion of the probable behaviour of the hydrogen in solution after solidification of the weld. Lepp's paper on the same subject (*Journal of The Iron and Steel Institute*, 1940, No. I, p. 329) is also discussed and is shown to lead to similar results for liquid iron.

The influence of micro-cavities and of inclusions is discussed, with particular reference to the influence of the active FeO content of the inclusions. It is confirmed that the baking of an electrode at 350° C. will reduce the hydrogen content in the resultant weld, but attention is drawn to the simultaneous change in the oxygen content which may occur.

CONSIDERABLE attention is being directed at present in several laboratories to the measurement of the hydrogen content of weld metal. Partly this is due to the considerable theoretical interest of the problem of the effects of this element on carbon and alloy steels, but chiefly it arises from the very practical and established fact of the influence of this gas on the cracking of welds, particularly in the hardened zones of welded high-tensile steels.

It is impossible in this short paper to enter in great detail into the metallurgical aspects of the welding of high-tensile steels, which have been discussed very fully during the last few years.⁽¹⁻⁴⁾ A brief summary of the main results is necessary, however, for an understanding of the part played by hydrogen in the cracking which may occur when these steels are welded.

INFLUENCE OF HYDROGEN IN THE WELDING OF HIGH-TENSILE STEELS.

It was shown by Swinden and Reeve in one of the earliest of these investigations⁽¹⁾ that a most important factor in the welding of high-tensile steels was the marked tendency for serious hardening to occur in the plate metal immediately adjacent to the welds. Under conditions of

* Received January 17, 1945.

restraint, serious cracking could occur in these hardened zones. Considerable study was devoted to methods of avoiding such cracking, and suitable welding techniques were evolved to this end. The two main lines of attack were:

- (1) To reduce the degree of hardening below certain limits by suitable control of the steel analysis, and by the deposition of the heaviest runs of weld metal possible; and
- (2) the development of suitable welding electrodes, relatively free from cracking tendency.

In connection with the latter point, Swinden and Reeve⁽¹⁾ reported, and it has since been confirmed by several other investigators,^(2, 4) that two types of electrodes produced welds which were relatively immune from cracking in the hardened zone even in severely restrained welded joints. These electrodes were:

- (1) "Soft" or oxidized mild-steel electrodes;
- (2) electrodes depositing fully austenitic weld metal of the high-nickel-chromium type.

Soft electrodes were defined as those containing less than 0.10% of carbon, less than 0.30% of manganese and less than 0.05% of silicon. A more exact definition is given later in this paper.

It was suggested that the reason for the success of these electrodes in preventing cracking was that the welds which they produced developed more favourable stress conditions on cooling.

Very few accurate measurements of the stress distribution adjacent to welds in relation to type of electrode have been carried out, but the little work that has been done to date (*e.g.*, by Professor Hanson and his co-workers⁽⁵⁾) on austenitic welds does not support the hypothesis that differences in this stress distribution are the main cause of the more favourable results obtained. It has been shown by Hopkin and other investigators^(6, 7, 8) that the tendency to produce cracking is influenced by the amount of moisture and other hydrogen-producing constituents in the coatings of the electrode. Thus, the baking of electrodes at elevated temperatures usually improves their resistance to cracking, whilst the addition of moisture detracts from it.

Ferritic electrodes have been designed with coatings low in sources of hydrogen, and are stated to show a marked improvement as regards cracking tendency.⁽⁷⁾

It is therefore probable that cracking in the hardened zones of welded high-tensile steel is produced by a combination of:

- (a) Hardened martensitic areas;
- (b) suitable stress conditions (which may produce initiating micro-cracks); and
- (c) a flow of hydrogen from the weld into this hardened zone, where it produces sufficient internal pressure to induce major cracking.

Austenitic welds are relatively free from cracking tendency, owing to the greater solubility of hydrogen in austenite (*see* Rollason⁽⁷⁾), whilst Hopkin⁽⁶⁾ and others have shown that the sensitivity of austenitic weld metal varies between different types, depending upon their hydrogen-containing constituents.

The freedom of dead soft or oxidized electrodes from cracking is ascribed to the presence of blow-holes, which retain the hydrogen as molecular or non-diffusing hydrogen, and also to the oxidation of some of the hydrogen to steam, the net result being a lower hydrogen content

diffusing into the hardened zone. Diffusing hydrogen is regarded as being in the atomic form (Hopkin⁽⁶⁾).

It will be seen that a broad basis for the hydrogen theory of cracking of the hardened zone of welds has been laid down, but greater quantitative information is obviously desirable before it can be said to be fully established.

It should be mentioned that the more oxidized weld metals are not only more immune to hard-zone cracking (when welding high-tensile steels), but are also less sensitive to welding cracks associated with high sulphur and high carbon contents. A fuller discussion of this aspect of weld cracking (in which hydrogen does not necessarily play a controlling part), will be given by the author in another paper now in course of preparation.

HYDROGEN DETERMINATIONS.

Some data on the hydrogen content of different types of electrodes have been reported by Rollason.⁽⁷⁾ A more detailed report by Sloman and Rooney on four electrodes, including their oxygen contents determined by vacuum fusion and iodine extraction, is in course of preparation.

The author, in conjunction with the Central Research Department of The United Steel Companies, has been carrying out similar determinations for several years, and the results for twelve different welds, graduated in accordance with their FeO content as determined by the fractional vacuum-fusion method,^(9, 10) are presented in Table I. The most oxidized electrodes, *K*, *L*, *M* and *A*, are at the top of the list and the least oxidized ones at the bottom. The hydrogen contents were also determined by vacuum fusion. "Low-temperature" or diffusible hydrogen was measured separately in each case by placing a pad of weld metal under mercury in the apparatus shown in Fig. 1 immediately after deposition. The pad was approximately 6 cm. long and 1.5 cm. square, and weighed approximately 100 g. As far as possible, the conditions of welding the pad were standardized as regards current, size of electrode, and time interval elapsing between the separate runs. Originally room-temperature evolution only was measured, but as the later stages of this evolution are extremely slow, occupying a period of many days, the practice finally established was to heat the specimen in the mercury to 230–250° C. with the aid of the small electric furnace shown. Under these conditions, practically all the low-temperature hydrogen is evolved within the first 5 hr., but as a precaution the specimen is allowed to cool overnight and heating is repeated on the following day for another 5 hr., making 10 hr. heating in all.

A vacuum heating apparatus similar to that described by Stevenson and Speight⁽¹¹⁾ is now being installed, and, when completed, it is proposed to determine more exactly whether the volume of gas evolved in 10 hr. at 250° C. is identical with that evolved at room temperature over a much

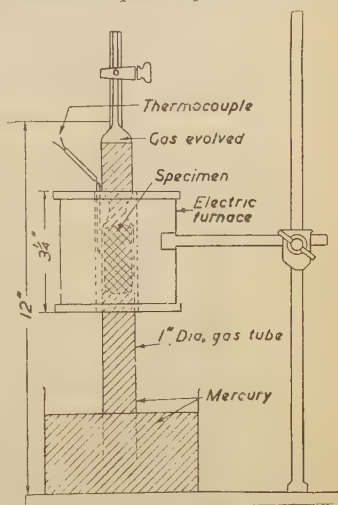


FIG. 1.—Apparatus for the Determination of Diffusible Hydrogen in Weld Metal.

TABLE I.—Oxygen, Nitrogen, and Hydrogen Content of Welds.

Electrode Type.	All-Weld-Metal Analysis.						Oxygen.				Nitrogen, Total, %.	Hydrogen, O.c. per 100 g.	
	C. %.	P. %.	Mn. %.	S. %.	Si. %.		FeO. %.	MnO. %.	SiO ₂ . %.	Al ₂ O ₃ . %.	Total Oxygen. %.	Diffusi- ble.	By Vacuum Fusion.
K ₁ Dead soft	0.04	0.025	0.02	0.024	Trace		0.859	0.013	0.0035	0.0095	0.200	1.53	10.2
K ₂ " "	0.04	...	0.02	...	Trace		...	...	...	...	...	Trace	...
L " "	0.03	...	0.02	...	Trace		0.916	0.015	0.0055	0.0015	0.211	Trace	9.2
M " "	0.03	...	Trace	...	Trace		...	...	...	...	...	Trace	...
A Soft	0.04	0.025	0.14	0.036	Trace		0.723	0.0375	0.0095	0.0045	0.1765	2.0	7.4
B Soft class A	0.07	0.034	0.33	0.034	0.028		0.181	0.189	0.055	0.075	0.148	1.28	13.6
H ₁ Class A, general pur- pose	0.05	0.045	0.32	0.035	0.056		0.086	0.106	0.0165	0.013	0.058	...	6.1
G ₁ G baked at 350° C.	0.05	0.035	0.34	0.026	0.085		0.077	0.090	0.0155	0.009	0.0505	2.7	3.1
C Class A, general pur- pose	0.06	0.028	0.33	0.035	0.085		0.068	0.127	0.048	0.041	0.089	2.02	10.0
D Class A, butt-welds	0.09	0.041	0.39	0.029	0.038		0.046	0.151	0.085	0.0125	0.095	3.85	17.6
G Class A, general pur- pose	0.05	0.035	0.40	0.023	0.132		0.036	0.122	0.032	0.011	0.0575	6.5	16.0
F Class A, butt-welds	0.08	0.030	0.29	0.040	0.118		0.024	0.124	0.042	0.020	0.0655	4.95	13.2
N Class A, high-tensile (Mo, 0.35%)	0.08	0.028	0.43	0.025	0.165		0.024	0.098	0.044	0.044	0.0714	6.4	14.0

longer period. At present all that can be said is that the volumes are known to be approximately equal.

In this connection, duplicate experiments on several welds have been found to agree to within about 20% of the gas volume, which, in view of the known heterogeneity of weld metal, must be regarded as fair agreement. It is known that the upper part of a butt-welded joint, for example, contains more FeO and less hydrogen than the lower part of the same weld; welding conditions (*e.g.*, current, arc length, &c.) no doubt also influence the results to some extent.

With the exception of electrodes *A*, *C*, and *F*, which were produced in the author's laboratory, all the electrodes used are commercial types supplied by well-known manufacturers.

RELATION BETWEEN HYDROGEN AND OXYGEN CONTENT.

It will be noted that the hydrogen by vacuum fusion ranges from 6.1 to 17.6 c.c. per 100 g., and that there is no very clear relationship between the total hydrogen and the total oxygen content, or between the total hydrogen and the FeO content, though on the average the most oxidised electrodes *K*, *L*, *M*, and *A*, are lower in total hydrogen than the others.

There is, however, a much closer relationship between the low-temperature or diffusible hydrogen (*H*)*D*, and the FeO content of the steel, as

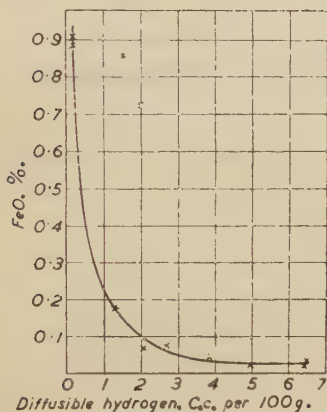


FIG. 2.—Relation between Diffusible Hydrogen and FeO Content of Weld Metal.

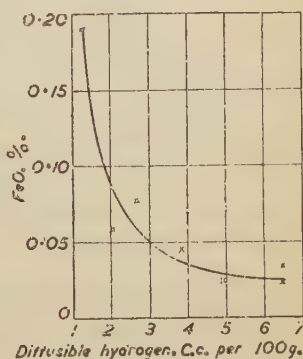


FIG. 3.—Relation between Diffusible Hydrogen and FeO Content of Weld Metal. (Part of Fig. 2 on larger scale.)

shown in Fig. 2 and, on a larger scale (up to 0.20% of FeO), in Fig. 3. The relation is approximately hyperbolic, $(\text{FeO}) \times (H)D$ being very roughly a constant, as shown in Table II. The four heavily oxidized electrodes, *K*, *L*, *M*, and *A*, have been omitted from the Table, as their exact $(H)D$ values are doubtful (*see later*). Qualitatively, however, their diffusible-hydrogen values are of the right order, being generally very low, in line with the high FeO content of these welds.

Electrode *B* in Table I. may be regarded as being at the limit of the oxidized type of electrode. In actual fact it is a well-known general-purpose electrode, not in the fully soft class, but known to be fairly immune in practice from cracking difficulties, both in the weld and in the plate-hardened zone. Electrodes *K*, *L*, *M*, and *A* are of the soft or dead soft type, and are capable of welding many high-tensile alloy and high-carbon

TABLE II. — *Relation between Diffusible Hydrogen, (H)D, and FeO Contents of Welds.*

Electrode.					FeO. %.	(H)D. C.c. per 100 g.	FeO \times (H)D.
B	.	.	.	.	0.181	1.28	0.23
C	.	.	.	.	0.068	2.02	0.14
G ₁	.	.	.	.	0.077	2.7	0.21
D	.	.	.	.	0.046	3.85	0.18
G	.	.	.	.	0.036	6.5	0.23
F	.	.	.	.	0.024	4.95	0.12
N	.	.	.	.	0.024	6.4	0.15
					Average		0.18

steels (and also high-sulphur steels) without cracking. As already mentioned, these completely oxidized types contain only small quantities of diffusible hydrogen, though still being fairly high in hydrogen (determined by vacuum fusion).

It should be stated, however, that in one test on electrode *K*, a small quantity of hydrogen (1.53 c.c. per 100 g.) was evolved very soon after immersion under the mercury, though a repeat test on another pad, *K*₂, gave zero hydrogen. The weld metal from this electrode was porous, and it is possible that this hydrogen was actually non-diffusible but had evolved from pores close to, or in contact with, the surface.

Electrode *L*, though equally soft as judged by chemical analysis, was free from obvious porosity, and, as shown in Table I., gave no diffusible hydrogen whatever.

Some complications may therefore arise in distinguishing between diffusible and total hydrogen in those cases where considerable weld porosity is present. It is probable, however, that this will arise only in the extreme case of fully oxidized electrodes. In practice these are likely to be less important than the partially oxidized electrodes similar to *B* and *C*, where porosity is relatively slight, and where this particular difficulty regarding the measurement of diffusible hydrogen content has not yet arisen.

Further tests are now proceeding which may modify the above conclusions in detail, but the broad outline of the relationship between the diffusible-hydrogen and FeO contents of weld metal seems to be fairly clear. It is probable that a similar relationship applies to steels made on a larger scale than weld metal, but further work will be necessary to confirm this.

THEORETICAL DISCUSSION OF RESULTS.

That some relation exists between the FeO content of steel and its hydrogen content has long been suspected. A similar relationship in the case of oxidized copper has been known for some time (Allen and Hewitt⁽¹²⁾), but no experimental confirmation has been established for steel. The nearest approach to a solution for steel has been provided by the experimental and theoretical work of Chipman and his collaborators,^(13, 14) which has been further amplified in a theoretical paper by Lepp.⁽¹⁵⁾ Unfortunately, the methods of calculation used by the latter were needlessly complicated, as was pointed out in the discussion on his paper, particularly by Phragmén.

Hydrogen-Steam Equilibria over Liquid Iron.

It will be shown below that the quantity of hydrogen in liquid iron in equilibrium with FeO in solution can be calculated by simple methods from Chipman's equilibrium data and Sieverts' law, both of which are based upon

experimental determinations. It will also be shown that Lepp's equations, slightly modified, will give similar results.

The method of calculation employed is to make use of two sets of experimental data, *viz.* :

(1) The data of Chipman and his co-workers^(13, 14) on the equilibrium $\text{Fe-FeO-H}_2\text{-H}_2\text{O}$; and

(2) Sieverts' data on the solubility of hydrogen in liquid iron, together with the related Sieverts' law.

Chipman and his co-workers have shown in a series of brilliant experimental investigations that equilibrium in the reaction :



at liquid-iron temperatures is governed by the simple equilibrium constant

$$K = [\% \text{ FeO}] \frac{(\text{H}_2)}{(\text{H}_2\text{O})}$$

The value of this constant was determined by them by circulating steam-hydrogen mixtures over molten electrolytic iron in the temperature range 1550–1770° C., finally analysing the iron melt for oxygen by the vacuum-fusion method. From these results it was shown that in this temperature range :

$$\text{Log } K = -\frac{10,200}{T} + 5.50.$$

The relations between $\text{H}_2/\text{H}_2\text{O}$ in the equilibrium gases and the FeO content of the iron at 1550°, 1600°, and 1700° C. have been calculated from Chipman's data and are given in Table III. It is obvious from these figures that the percentage of hydrogen in the equilibrium gases falls as the content of FeO in the iron increases. It also falls as the temperature is reduced.

TABLE III.—Chipman's Data for Values of $\text{H}_2/\text{H}_2\text{O}$ Ratios Over Liquid Iron Containing Dissolved FeO.

FeO. %.	Equilibrium Ratio $\text{H}_2/\text{H}_2\text{O}$ at—		
	1550° C.	1600° C.	1700° C.
0.01	81.0	114.0	213.0
0.02	40.0	57.0	108.0
0.05	16.1	22.7	43.0
0.10	8.1	11.4	21.5
0.20	4.0	5.7	10.8
0.50	1.6	2.3	4.3
1.00	0.81	1.14	2.15

It may be surmised from these data that the quantity of hydrogen dissolved in the iron will also fall as the quantity of oxygen in it increases, but Chipman (who was mainly concerned with the gaseous equilibria) did not determine the amount of hydrogen dissolved in his specimens.

Hydrogen Content of Liquid Iron in Presence of Dissolved FeO.

The amount of hydrogen in solution in the molten iron at these temperatures can be calculated from Table III. by applying Sieverts' law (*i.e.*, solubility is proportional to the square root of the hydrogen pressure), together with his solubility determinations of hydrogen in liquid iron,⁽¹⁶⁾ *viz.* :

Hydrogen Solubility in Liquid Iron at 1 Atm. (Sieverts).

Temperature	.	.	.	1550° C.	1600° C.	1700° C.
Hydrogen solubility	.	.	.	0.00252%	0.00267%	0.00293%

TABLE IV.—*Solubility of Hydrogen in Liquid Iron at 1550°, 1600°, and 1700°C. in the Presence of Dissolved FeO.*

FeO. %.	Hydrogen.		
	In Equilibrium Gas. Atm.	In Metal. %.	In Metal. C.c. per 100 g.
<i>1550° C.</i>			
0.01	0.988	0.00250	27.8
0.02	0.977	0.00249	27.7
0.05	0.943	0.00244	27.2
0.10	0.890	0.00238	26.4
0.20	0.800	0.00225	25.0
0.50	0.616	0.00197	21.9
1.00	0.448	0.00168	18.7
<i>1600° C.</i>			
0.01	0.992	0.00266	29.6
0.02	0.984	0.00265	29.5
0.05	0.958	0.00262	29.1
0.10	0.920	0.00257	28.6
0.20	0.852	0.00247	27.5
0.50	0.697	0.00223	24.8
1.00	0.533	0.00195	21.7
<i>1700° C.</i>			
0.01	0.996	0.00292	32.6
0.02	0.993	0.00291	32.4
0.05	0.979	0.00289	32.2
0.10	0.957	0.00287	32.0
0.20	0.917	0.00281	31.3
0.50	0.812	0.00264	29.4
1.00	0.683	0.00242	27.0

A total pressure of $H_2 + H_2O$ of 1 atm. in the gases surrounding the iron will be assumed. The results of these calculations are shown in

Table IV. and Fig. 4. For purposes of comparison with the author's experimental data, the percentage of hydrogen has been recalculated in the last column in terms of cubic centimetres per 100 g. of iron.

Similar results to those reported above can be obtained from equation (7) of Lepp's paper.⁽¹⁵⁾ Modified slightly in the light of Phragmén's criticism, it is as follows:

$$K = \frac{(H_2O)^2}{[\% FeO]^2 [\% H]^2 (H_2)}$$

$$\text{and } \log K = \frac{23,580}{T} - 7.55.$$

The constituents in solution in the molten iron have been placed in square brackets, and the gaseous constituents, expressed in atmospheres, in round brackets. T is the absolute temperature.

If this equation is used in conjunction with Chipman's equilibrium data

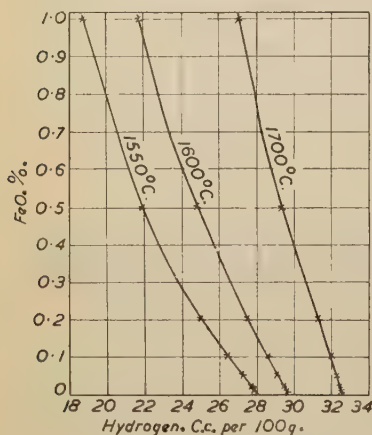


FIG. 4.—Solubility of Hydrogen in Liquid Iron in the Presence of Dissolved FeO.

for $(\text{H}_2)/(\text{H}_2\text{O})$ to calculate solubilities in the presence of, say, 1% of FeO, the following results will be obtained :

Hydrogen Solubility in Liquid Iron containing 1% of FeO (calculated by Lepp's equation).

Temperature	:	:	1550° C.	1600° C.	1700° C.
Hydrogen content	:	:	0.0016%	0.0018%	0.0024%

These results are almost identical with those reported in Table IV. Phragmén, in his discussion, quotes a figure of 0.0018% hydrogen in solution in liquid iron at 1600° C. when saturated with FeO, as compared with 0.0026% in molten iron free from FeO. These figures are again in line with the results of the author's calculations in Table IV.

Before leaving Lepp's results, it should be pointed out that in Fig. 5 of his paper,⁽¹⁵⁾ he made the serious mistake of extending his calculations based upon the afore-mentioned equation to FeO contents in solution in liquid iron as high as 30%. Such solutions, as pointed out by Phragmén, are incapable of being obtained in actual fact, and, no doubt realizing this, Lepp tried to get out of the difficulty by extending his deductions to liquid steel in contact with *slags* containing "about 20% of FeO." If he had confined his calculations to values of [FeO] up to about 1.0% he would have obtained very similar curves to the present author's, and Phragmén's criticisms would no longer have applied.

Referring again to Table IV., it will be noted that the total hydrogen in solution in oxidized iron, or weld metal, at the melting point will be quite appreciable. In fact, the amount in the most highly oxidized weld metal containing about 1% of FeO should be about 60% of that in weld metal practically free from FeO. This, broadly speaking, is confirmed by the experimental data in Table I., in which, as already pointed out, the total hydrogen content of fully oxidized weld metal, though lower than in less oxidized types, is still quite appreciable. The magnitude of the experimental values reported here corresponds very approximately to the theoretical figures in Table IV. for molten iron at about 1550° C. Closer agreement cannot be expected without more detailed knowledge of the partial pressures of hydrogen and H_2O in the gases surrounding the welding arc, concerning which little is known (see Larsen⁽¹⁷⁾).

Hydrogen Equilibria in the Solid Weld.

We must now consider what happens to the hydrogen in the weld after solidification. Here the position is more complex and less amenable to exact treatment. Neither Chipinan's data nor Lepp's calculation, which apply to liquid iron only, are of much assistance for the exact solution of this problem, and the following discussion covers only its broad outlines.

It is suggested that, despite the rapid rate of cooling, equilibrium between hydrogen, H_2O , and FeO in the solid weld tends to be established, but is modified by the effects of solidification. These are :

(1) Numerous FeO inclusions or compound oxides and silicates containing FeO are thrown out of solution. A very small amount of oxygen remains in solution.

(2) Hydrogen remains in solution, but tends to diffuse into the microscopic cavities between the inclusions and the weld metal, and into blow-holes and other voids. At elevated temperatures, where the permeability is high, some exchange of hydrogen between the cavities and the iron lattice will no doubt take place, but this will be less marked as the temperature falls. At lower temperatures hydrogen can diffuse into these cavities, but will diffuse out of them only very slightly. The greater the number of these voids the larger is the amount of hydrogen finally left in the non-diffusible form.

(3) The well-established data for the equilibrium between solid FeO, iron, hydrogen, and H_2O , which have been investigated by numerous workers, will apply to the hydrogen which has diffused into the space adjacent to inclusions containing FeO. The greater the amount of the reducible FeO in these inclusions (*i.e.*, the greater the activity of the FeO), the larger is the percentage of this hydrogen converted to H_2O , the limiting factor being the equilibrium ratio H_2/H_2O for the solid system Fe-FeO. (The value of this equilibrium ratio is approximately unity at a temperature of $1200^\circ C.$, falling with decrease of temperature.)

(4) The H_2O produced in the cavity is probably incapable of diffusion out of it, even at elevated temperatures, whereas the hydrogen, as already explained, is subject to such balanced diffusion. The net result is that more hydrogen will enter such cavities to adjust the hydrogen balance between lattice and void, rather on the lines of the well-known osmotic action across semi-permeable membranes. Hence, inclusions containing FeO will tend to attract a larger quantity of hydrogen than inclusions not containing FeO.

(5) The net result is that the proportion of non-diffusible hydrogen will be the greater, the larger the number of inclusions (or other micro-voids) and the larger their reducible FeO content.

It follows that some of the non-diffusible hydrogen in welds must actually be H_2O —possibly as much as 50% of it. It would be of the greatest interest to be able to determine this constituent separately. Neither the vacuum-fusion nor the vacuum-heating method is capable of distinguishing between hydrogen and H_2O . In the vacuum-fusion method H_2O will react with the graphite crucible to form CO and hydrogen. In the vacuum-heating method the equilibrium mixture of hydrogen and H_2O in the voids will lose hydrogen by diffusion, whereupon the remaining H_2O will react with iron to produce more hydrogen, until practically all the H_2O diffuses out as hydrogen. (It is most unlikely that H_2O could diffuse as such through the iron lattice.) Both Stevenson⁽¹¹⁾ and Newell⁽¹⁸⁾ have reported steam in the gases collected in the vacuum heating of steel, but both state that this may have been derived from sources other than the steel or by reaction with surface oxygen.

Returning to the question of the quantity of non-diffusible hydrogen, this should be quite appreciable even in welds free from FeO, since they contain micro-voids, associated with other inclusions than FeO, and also blow-holes and similar micro-cavities. That this is actually the case will be seen from Table I., where even in the welds practically free from FeO (*e.g.*, *G* and *F*) the proportion of non-diffusible hydrogen is as high as two-thirds of the total, less than one-third being diffusible. As the weld becomes more oxidized the percentage of diffusible hydrogen falls to less than 5% of the total, for the reasons already stated.

If this general argument is substantially correct, the amount of diffusible hydrogen in a weld (or steel) is a sensitive measure of its FeO content—much more so than its total hydrogen content.

TOTAL AVAILABLE HYDROGEN IN ELECTRODE COATINGS.

It is reasonable to suppose that, apart from control of hydrogen by variation of the FeO content, the quantity of hydrogen in welds could also be reduced by decreasing the quantity of available hydrogen in the electrode coatings, also in the form of free and combined water, and as organic hydrogen in the form of cellulose and similar materials. It has, in fact, been suggested that there should be an exact relationship between the total hydrogen in the weld and the available hydrogen in the coating expressed

as a percentage of the weight of the steel core. This, in the author's view, is improbable, since the percentage of hydrogen in the gases surrounding the arc will not necessarily vary directly as the hydrogen content of the coating. The amount of H_2O , CO , and CO_2 in these gases is likely to differ considerably for different types of electrodes.

The percentage of available hydrogen for most of the electrodes listed in Table I. has been determined by combustion of their coatings in oxygen and weighing the resultant H_2O . The results are shown in Table V., together with the corresponding *total* hydrogen in the welds (diffusible plus vacuum fusion). It is clear that the correlation between the two sets of figures is slight. Nevertheless, it has been confirmed that baking electrodes to remove some of the hydrogen-forming constituents will reduce the hydrogen in the weld. This has been done in the case of electrode G_1 , which is the same as electrode G in Table I., except that it had been baked at $300-350^\circ C.$ for one hour. The effect of this baking has been to reduce the available hydrogen from 0.48 to 0.19% of the weight of the steel core, whilst the diffusible hydrogen has fallen from 6.5 to 2.7 c.c. per 100 g., and the vacuum-fusion hydrogen from 16.0 to 3.1 c.c. per 100 g. (Table I.).

TABLE V.—*Hydrogen in Electrode Coatings.*

Electrode Type.	Ratio of Coating to Steel. %.	Hydrogen in Coating.		Total Hydrogen in Weld. C.c. per 100 g.
		%.	C.c. per 100 g. of steel.	
<i>L</i>	25.96	0.47	1524	9.2
<i>A</i>	20.81	0.58	1313	9.4
<i>B</i>	17.82	0.96	1904	14.9
G_1 (baked $350^\circ C.$)	20.45	0.19	472	5.8
<i>C</i>	20.31	0.62	1401	12.0
<i>D</i>	24.36	0.61	1383	21.45
<i>G</i>	22.26	0.48	1190	22.5
<i>F</i>	11.79	0.92	1207	18.15
<i>N</i>	13.07	1.96	2850	20.4

Such baking must be carried out with care and discretion, however, or the chemical analysis of the weld metal, together with its oxygen content, may also be affected, and this, in turn, may affect the hydrogen content. This has occurred to an appreciable extent in the present case, as will be seen from Table I. Although the total oxygen is practically unchanged, the FeO content of the baked electrode G_1 has increased, *i.e.*, it has become more oxidized. The cracking tendency of this electrode has not yet been tested, but it will not be surprising if it is found to be less sensitive to hard-zone cracking. Further discussion of this point is obviously premature, and will be taken up when more information is available.

CONCLUSIONS.

(1) The diffusible hydrogen content of weld metal has been shown by several investigators to have some influence on the cracking of the hardened zones in welded high-tensile steels.

(2) The most important result of the investigation reported in this paper is the demonstration of the relationship between the FeO content of weld metal and its total and diffusible hydrogen contents. The total hydrogen content will be slightly reduced, whilst the diffusible hydrogen will be considerably reduced, with increasing FeO in the weld metal. Similar conclusions will presumably apply to steels made by other steelmaking processes, though this has not yet been established experimentally.

(3) An attempt has been made to explain these results on the basis of the data reported by Chipman for the system $\text{Fe-FeO-H}_2\text{-H}_2\text{O}$ at temperatures above the melting point and of a discussion of the probable behaviour of the hydrogen in solution after the solidification of the weld. Lepp's paper on the same subject, though unnecessarily complex in its methods of calculation, leads to similar results for liquid iron, but does not consider the more complex behaviour of the hydrogen after the weld solidifies.

(4) The influence of voids or micro-cavities surrounding different types of inclusions, and voids due to blow-holes, &c., has been discussed, with particular reference to the influence of the active FeO content of the inclusions.

(5) The total available hydrogen content of electrode coatings in the form of free and combined water and as organic hydrogen must in the long run influence the total quantity of hydrogen entering the weld, but it is shown that the relationship is not very close. It is confirmed, however, that controlled baking of an electrode at 350°C . will reduce the available hydrogen in the coating and the total and diffusible hydrogen in the weld.

ACKNOWLEDGMENTS.

The assistance of Mr. E. D. Harry, B.Sc., of the Appleby-Frodingham Research Department, who carried out the diffusible hydrogen determinations, and of Mr. W. W. Stevenson, F.R.I.C., and Mr. G. E. Speight, B.Sc. of The United Steel Companies' Central Research Department, who were responsible for the vacuum-fusion analyses, is gratefully acknowledged.

The Management of the Appleby-Frodingham Steel Co., Ltd., must also be thanked for their kind permission to publish this paper.

REFERENCES.

- (1) SWINDEN and REEVE : *Transactions of the Institute of Welding*, 1938, vol. 1, Jan., pp. 7-24.
- (2) WILKINSON and O'NEILL : *Transactions of the Institution of Mechanical Engineers*, 1939, vol. 141, No. 6, pp. 497-518.
- (3) REEVE : *Transactions of the Institute of Welding*, 1940, vol. 3, Oct., pp. 177-202.
- (4) ROLLASON, COTTRELL, WINTERTON, and CROWTHER : *Transactions of the Institute of Welding*, 1941, vol. 4, Jan., pp. 3-21.
- (5) HANSON, COTTRELL, WINTERTON, CROWTHER, and WHEELER : *Transactions of the Institute of Welding*, 1944, vol. 7, July, pp. 43-74.
- (6) HOPKIN : *Transactions of the Institute of Welding*, 1944, vol. 7, July, pp. 76-78.
- (7) ROLLASON : *Transactions of the Institute of Welding*, 1944, vol. 7, July, pp. 74-75.
- (8) ZAPFFE and SIMS : *Journal of the American Welding Society*, 1940, vol. 19 (Supplement), Jan., pp. 377 s-395 s.
- (9) REEVE : *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1934, *Iron and Steel Division*, vol. 113, p. 82.
- (10) SWINDEN, STEVENSON, and SPEIGHT : *Journal of The Iron and Steel Institute*, 1941, No. I., pp. 312 P-320 P.
- (11) STEVENSON and SPEIGHT : *Journal of The Iron and Steel Institute*, 1943, No. II., pp. 290 P-297 P.
- (12) ALLEN and HEWITT : *Journal of the Institute of Metals*, 1933, vol. 51, p. 257.
- (13) FONTANA and CHIPMAN : *Transactions of the American Society of Metals*, 1936, vol. 24, p. 313.
- (14) CHIPMAN and SAMARIN : *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1937, vol. 125, pp. 331-345.
- (15) LEPP : *Journal of The Iron and Steel Institute*, 1940, No. I., pp. 329 P-339 P.
- (16) SIEVERTS : *Zeitschrift für physikalische Chemie*, 1911, vol. 77, p. 591.
- (17) LARSEN : *Journal of the American Welding Society*, 1936, vol. 15, Oct., p. 17.
- (18) NEWELL : *Journal of The Iron and Steel Institute*, 1940, No. I., pp. 243 P-253 P.

CORRESPONDENCE.

Mr. H. A. SLOMAN and Mr. T. E. ROONEY (National Physical Laboratory, Teddington) wrote: We have read Dr. Reeve's most recent contribution to the study of the problem of the cracking of weld metal with very great interest. This phenomenon is one of considerable practical importance, in which hydrogen is known to play a part. Any information which gives us a better understanding of the rôle which this gas plays in determining the properties of weld deposits is thus most welcome.

Dr. Reeve's paper was published by The Iron and Steel Institute almost simultaneously with one by our colleague—Mr. T. H. Schofield—and ourselves * on a practically identical aspect of the problem, and it may appear at first sight that some mutually contradictory conclusions have been reached. It is, therefore, not inappropriate that attention should be drawn to certain differences in technique, &c., between the two investigations.

Let us consider first the determinations of the amounts of hydrogen in weld deposits. As was done in the work at the N.P.L., the author determined the hydrogen in the weld deposits in two fractions; first, that part—called diffusible hydrogen—which is evolved at low temperatures, and, secondly, the remainder, which can only be extracted at elevated temperatures. The sum of these two fractions gives the total hydrogen in the deposit. Whereas, however, at the N.P.L. the diffusible hydrogen was measured by extraction in a vacuum at room temperature, Dr. Reeve used a temperature of about 250° C. with the specimen immersed in mercury. He states that he believes the total amount of hydrogen evolved at room temperature is approximately equal to that extracted at 250° C. On this point we are doubtful, believing in fact that considerably more total gas is likely to be evolved at the higher temperature. In support of this view, we should like to cite Johnson, Arner, and Schwartz † who, in a recent paper, have published the results of actual comparative measurements carried out at room temperature and at 200° C. on samples of cast steel. In some of their experiments all the hydrogen which could be extracted from a sample at room temperature was given sufficient time (many days) to be evolved and the temperature was then raised to 200° C. Considerable further quantities of hydrogen were evolved. In other experiments two similar samples were examined, one at room temperature and the other at 200° C. Again the sample held at 200° C. evolved more hydrogen than did the one held at room temperature. There is, therefore, a very strong possibility that the author has not measured the true room-temperature diffusible hydrogen and that his results and those obtained at the N.P.L. are not strictly comparable. We are very glad to note that the author proposes to conduct some further experiments to throw more light on this point.

With regard to his measurements of diffusible hydrogen, Dr. Reeve remarks that duplicate experiments gave results agreeing to within about 20%, whereas one of the most striking results in the work at the N.P.L. was that while the total hydrogen (*i.e.* diffusible plus residual) was found to remain constant in duplicate experiments, the diffusible portion (and hence also the residual portion) varied largely. Citing some figures from our paper, the diffusible hydrogen in a series of welds made with the same electrode ranged from 1.4 to 3.1 ml. per 100 g. while the total remained

* Sloman, Rooney, and Schofield, "A Preliminary Investigation of the Constitution of Mild-Steel Arc-Weld Deposits," *Journal of The Iron and Steel Institute*, 1945, No. II., p. 127 P (this volume).

† Johnson, Arner, and Schwartz, "Gas Evolution from Cast Steel at Room Temperature," *American Society for Metals*. Preprint, 1945.

almost constant (8.2-8.6 ml. per 100 g.). After a considerable number of experiments we came to the conclusion that this variability in diffusible hydrogen from weld to weld was not controllable by the operator but "is due to a very fine porosity within the weld metal arising from causes about which very little is at present known, such as, for example, variations in the temperature or other electrophysical characteristics of the arc during welding."

One possible explanation of the difference between the author's experience and our own is that the extraction, at 250° C. in his case, may have masked the variations in the amounts extracted in the cold as noted at the N.P.L. In this connection it may be noted that in general Dr. Reeve's diffusible-hydrogen figures are larger than those obtained at the N.P.L. from weld samples made with similar types of electrodes.

Turning now to a consideration of the possible relation between total hydrogen (diffusible and residual) in a weld and the so-called potential hydrogen in the flux coating of the electrode, it was shown in the course of the N.P.L. investigation that, for the series of seven electrodes examined, approximate proportionality existed between the total hydrogen in weld samples laid down under standard conditions and the total potential hydrogen of the electrode coatings. In carrying out such work it is important that the whole series of comparative measurements should be made under the same, controlled, conditions. For example, it is essential that all the different electrodes should be in a standard state both at the time when potential-hydrogen measurements are made on the coatings and also when they are being used for the actual deposition of the weld samples. Again, the determinations of potential hydrogen must be carried out in such a way as to ensure that the whole of it is estimated.

In the present paper we have been unable to find any reference to these points. For instance, the temperature at which the combustions of the flux coatings in oxygen were carried out to give the potential-hydrogen values is not stated. In the N.P.L. investigation it was found that with some coatings there was very little difference between the potential hydrogen determined at 600° C. or at 1200° C., whereas with others the results at the higher temperature were considerably higher. Again, the author makes no mention of having subjected the electrode coatings to any standardizing treatment before use. Work at the N.P.L. and elsewhere has demonstrated that the moisture content (and hence the potential hydrogen) of a coating may vary greatly from time to time, depending on atmospheric conditions. Unless, therefore, some satisfactory method of storage and pretreatment is used throughout the investigation, the results are liable to be erratic and not necessarily comparable.

In view of the results obtained in the investigation at the N.P.L., the suggestion was advanced that the approximate proportionality between total hydrogen in a weld and potential hydrogen in the electrode coating might be found to be generally true. It was, of course, recognized that the correlation might be upset by disturbing influences in special cases, where, for instance, the composition of the arc atmosphere departs considerably from the normal. Dr. Reeve, however, considers that this relationship is not likely to be generally true and cites his own results in support of his argument. Of these results he says that "it is clear that the correlation between the two sets of figures is slight." Since the author appears to have taken no special care to keep conditions with regard to the points discussed above consistent throughout the investigation, a certain lack of consistency in his results was to be expected. Nevertheless, this lack of consistency does not seem to be as serious as the author would suggest in his statement quoted above.

Dr. Reeve does not give results for all the electrodes used in his in-

vestigation, but a series of nine is given in Table V. of the paper, and as a matter of interest we have plotted his values alongside our own. If there were no correlation between hydrogen in the weld and potential hydrogen in the coating, one would expect all nine results to be disposed in a completely haphazard manner, whereas in fact six of them fall almost as close to a straight line as do those obtained in the investigation at the N.P.L., while the other three points fall close together but away from the line (see Fig. A). The evidence provided by the six results which fall on a straight line is too strong to be ignored, and statistically the proportionality exhibited thereby cannot be ascribed purely to chance. The probable interpretation of the author's results would thus appear to be as follows: During the examination of the six electrodes and welds, conditions were approximately constant, whereas in the case of the other three, another set of conditions was operative. It is possible that the change in conditions arose for reasons unsuspected at the time when the work was carried out, as, for example, might arise under certain atmospheric conditions due to non-standardization of the coatings before use.

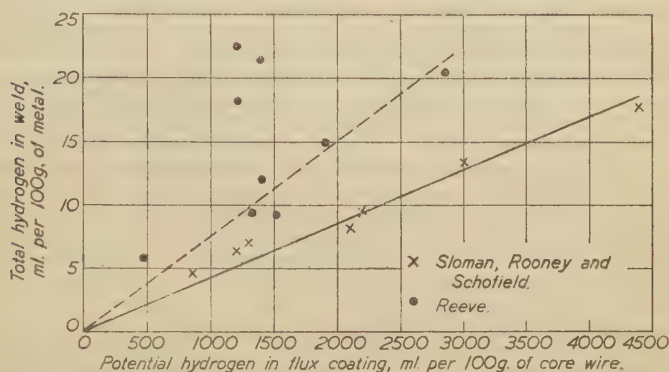


FIG. A.—Relation between Total Hydrogen in Weld and Potential Hydrogen in Flux Coating.

So far then from the correlation being slight, we suggest that the author's results tend to confirm the results obtained in the investigation at the N.P.L., and they strengthen the view expressed in our paper that the relationship under consideration may in general be approximately true. It is also of interest to note that the slope of the line we have drawn in Fig. A connecting Dr. Reeve's determinations is steeper than is the N.P.L. line. This is what we would have expected having regard to the sizes and types of weld samples used in the two investigations. It was pointed out in our paper that the slope of the line relating the total hydrogen contents of weld samples with the potential hydrogen contents of the coatings should depend on the particular form of sample employed, since this will determine the rate of cooling of the deposited metal and, in the case of multi-run samples, the heating effect of one run upon those previously laid down. The more slowly the weld metal cools or, alternatively, the larger the number of times the metal is reheated by the deposition of additional runs, the greater will be the proportion of the contained hydrogen which can diffuse away during the actual welding operation. Thus for a given potential hydrogen content in the coating, a single-run deposit, which cools very rapidly, will, at the time it reaches room temperature,

hold considerably more total hydrogen than would a large multi-run channel-type weld. The slope of the line characteristic of a series of single-run deposits should, therefore, be very steep, while that of a similar series of multi-run channel welds should be relatively slight. The samples employed in the investigation at the N.P.L. were in the latter category, whereas Dr. Reeve's smaller pad-type specimens occupy an intermediate position and would be expected to yield results which fall on a line of slope steeper than ours but not as steep as one for single-run specimens.

Turning now to the relation between hydrogen and oxygen, we are in full agreement with the author, if we read him correctly, when he ascribes the well-known porosity associated with the use of dead-soft or oxidized electrodes to a reaction between FeO and hydrogen with the generation of steam, such reaction taking place at the stage when the deposit is just solidifying and is mechanically weak. When such electrodes are used the weld metal undoubtedly contains a large amount of free iron-oxide inclusions and, during and after solidification, the reaction $\text{FeO} + 2\text{H} \rightarrow \text{Fe} + \text{H}_2\text{O}$ will take place with the formation of cavities due to steam pressure. Once these cavities have been formed some of the remaining hydrogen still dispersed in the atomic state throughout the metal will continue to diffuse into them as the weld cools to room temperature (and afterwards) where it will be trapped in the molecular form. Such hydrogen will not be diffusible in the cold, and one would, therefore, expect the major portion of the hydrogen in such welds to be non-diffusible. The points at the top of the curve in Fig. 2 of the author's paper are thus readily accounted for. When, however, one considers the more usual types of electrode it will be observed that at its lower end (high diffusible hydrogen) the shape of the curve in Fig. 2 is such as to make the amount of diffusible hydrogen very sensitive to small changes in the FeO content. It is immediately obvious that considerable accuracy in the determination of the FeO in samples made with these electrodes is of great importance in attempting to establish any relationship between FeO and diffusible hydrogen.

It was, therefore, in our view, most unfortunate that Dr. Reeve made use of the fractional vacuum-fusion method as a means of determining the FeO in his weld samples, since this method is still open to considerable doubt in the separation of FeO and MnO . The determinations were carried out for him in the Central Research Department of The United Steel Companies, Ltd., and, in their contribution to the latest (Fourth) Report of the Oxygen Sub-Committee, the operators of the method state that "one of the main difficulties of the method lies in the separation of iron and manganous oxides, which, even with pure and separate oxides, is incomplete." It would seem, therefore, that all the values for FeO and MnO in Table I. of the paper, with the exception of those which apply to dead-soft electrodes, are liable to considerable error.

However, taking the values in Table I. at their face value, it would still not be legitimate, as was shown in the N.P.L. investigation, to consider that the values in the column " $\text{FeO}, \%$ " necessarily represent iron oxide present in the free state. It would in fact be true to say that in examining welds made with the normal commercial types of mild-steel electrode we have never yet found any free FeO . Where free oxide does exist it is not pure FeO but a solid solution of iron and manganese oxides. Furthermore, in such cases this accounts for only a part of the oxygen which is present in association with iron, the remainder being present as an iron silicate of the fayalite type. In other cases there is no free oxide at all, the oxygen being present entirely as one of the manganese silicates in which iron has replaced a little of the manganese.

It thus appears that in welds made from normal commercial mild-steel

electrodes there is unlikely to be any free iron oxide, although in some cases iron-manganous oxide may be present. There is thus a strong probability that any apparent relationship in these cases between diffusible hydrogen and oxygen associated with iron is fortuitous.

One further point in this connection may be mentioned. Welds made with dead-soft or oxidized electrodes usually contain a large amount of visible porosity. It would, therefore, be expected that in such welds a very large proportion of the total hydrogen would be non-diffusible at room temperatures. On the other hand, the more normal types of commercial mild-steel electrodes produce deposits which usually appear almost completely sound even under the microscope. In such welds the greater proportion of the hydrogen should be diffusible, since there are very few obvious cavities in which it can be trapped. Yet, both in the present work and in the investigation at the N.P.L., this was not found to be the case. For example, in Table I. of the paper it will be seen that the amount of non-diffusible hydrogen is always greater, and in most cases considerably greater, than the diffusible portion irrespective of the type of electrode employed. The author makes no suggestion to explain this anomaly. Much, therefore, as we had hoped to the contrary, we feel the author has not advanced any new and acceptable explanation to account for the two forms of hydrogen (diffusible and non-diffusible) present in normal mild-steel weld metal which can replace that which was generally accepted before, namely, that the amount of non-diffusible hydrogen depends on the number and volume of minute, probably sub-microscopic, cavities present in the deposit. The way in which these cavities originate still remains to be elucidated.

AUTHOR'S REPLY.

Dr. REEVE wrote in reply : It is interesting to point out to Mr. Sloman and Mr. Rooney that on the one hand the experimental error of $\pm 20\%$ claimed by the author is regarded as being better than they would expect, whilst on the other hand the relationship between total hydrogen in the weld and the "available hydrogen," which is stated by the author to be "slight," is regarded by them as being "approximately true." The probable truth is that the inherent errors of this type of analysis are considerable, and if it were not for the theoretical considerations dealt with in considerable detail elsewhere in the author's paper, which strongly support the otherwise approximate experimental determinations, he would have hesitated to publish the latter.

But the support given to the experimental results by the theoretical discussions is considerable, and cannot be ignored. The author notes that Mr. Sloman and Mr. Rooney do not refer to the discussion of the equilibrium relations between FeO and hydrogen in *liquid* steel, the conclusions of which he assumes they have accepted. He also notes that they agree that reaction will take place in the case of fully oxidised or dead-soft electrodes between FeO and hydrogen when the deposit is "just solidifying and is mechanically weak." But why restrict reaction between FeO and hydrogen to temperatures of the order of $1500^{\circ}\text{C}.$? There is no reason why it should not continue down to much lower temperatures. If they agree with this simple hypothesis they must accept the remainder of the author's theory given on p. 394 p. Nor is there any reason for them to restrict the possibility of reduction by hydrogen to inclusions consisting of 100% FeO, as they would appear to do from their discussion at some length of the probability that pure FeO is not often present in weld metal.

Whether the FeO is pure or is partly or wholly combined with MnO or with sulphides or silicates is beside the point as long as such inclusions are

even partly reducible by hydrogen. This is quite clearly pointed out by the author at the bottom of p. 393 P, where he states that "FeO inclusions or compound oxides and silicates containing FeO" will be thrown out of solution from the solidifying weld, and at the top of p. 394 P, where he refers in two places to "reducible FeO."

In the author's view, one advantage of the fractional vacuum fusion method, apart from the important one of speed, is that it distinguishes between such "reducible FeO" and possibly more stable and only partially reducible FeO. The iodine extraction method is incapable of doing this. It is true that in the fractional method separation of the FeO and MnO fractions may not be complete, but this does not alter the fact that by the very nature of the method—*i.e.*, reduction by carbon at relatively low temperatures—the more reducible FeO is readily distinguished.

The general basis of the author's paper is that the degree of oxidation of welds as measured by their reducible FeO content (whether free or combined) is an important factor in deciding the quantity of non-diffusible hydrogen which such welds will yield. He suggests that this concept of degree of oxidation is a useful working hypothesis which has already given fruitful practical results. In this connection the author would draw Mr. Sloman and Mr. Rooney's attention to his paper on the influence of the degree of oxidation of the same types of weld metal on their sensitivity to sulphur cracking, which has appeared recently.*

Turning to some points of detail, the author notes the possibility that the quantity of diffusible hydrogen may be higher at 250° C. than at room temperature. He is willing to accept this possibility, but doubts whether the relative order of results will be seriously affected. A greater regularity of results at 250° C. may even be possible, as suggested by Mr. Sloman and Mr. Rooney. It is worth pointing out that in practice a portion at least of the hydrogen diffusing from a cooling weld will do so at temperatures in the neighbourhood of 250° C., as by the time the weld reaches this temperature it and the adjoining plate are cooling at a relatively slow rate. This may provide some additional justification for carrying out the hydrogen extraction tests at slightly elevated temperatures. The great advantage of working at 250° C. is the marked speeding-up of determinations, a consideration which cannot be ignored in an industrial laboratory. The author agrees, however, that further investigation of the relation between diffusion at 250° C. and at room temperature is necessary.

The temperature at which combustion of the flux coatings in oxygen was carried out was approximately 900° C., which should be ample to look after all potential hydrogen. At 600° C. combined water is likely to be retained, and low results are not surprising.

Finally, there is some contradiction in the last paragraph of Mr. Sloman and Mr. Rooney's comments, where they refer to an "anomaly" in the author's theory, when they ask what happens to the high proportion of non-diffusible hydrogen in deposits which "appear almost completely sound, even under the microscope?" Apart from the fact that it is not easy to judge the soundness of a weld by a micro-examination of its surface, they answer this query themselves at the end of the paragraph, where they state that "the amount of non-diffusible hydrogen depends on the number and volume of minute, probably sub-microscopic, cavities present in the deposit." The author fully accepts this latter explanation, with the important addition that he suggests that the cavities include the minute spaces surrounding inclusions, and that when such inclusions contain reducible FeO some of the non-diffusible hydrogen must be oxidised to water as the weld cools. This is clearly stated at the top of p. 394 P of the paper. Future investigation will show to what extent this concept helps in the development of the subject.

* *Transactions of the Institute of Welding*, 1945, vol. 8, No. 2, May, pp. 80-88.

THE DEVELOPMENT OF A SINGLE-BLOW IMPACT TEST FOR CAST IRON.*

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(Figs. 10 to 15 = Plates XL. and XLI.)

SYNOPSIS.

Applications of modern high-duty cast iron in the Services and in engineering practice generally often call for a measure of shock resistance, and the need has been felt for some time past for a simple test to evaluate this quality. A sub-committee of the Technical Advisory Panel to the Directors for Iron Castings, Ministry of Supply, was therefore set up to collaborate with the British Cast Iron Research Association in reviewing the work previously carried out in this field and to explore the possibilities of standardising a suitable test. After reviewing previous work it was decided that the Izod form of test offered the best possibilities and had the further advantage that suitable machines were widely available. The small test-piece, standard for steel, however, is useless for cast iron, owing to its relatively low impact value. Tests were put in hand, therefore, using larger test-pieces, with and without notches or grooves. Selected forms of test-piece were distributed to various investigators and the consistency of the results obtained on standard grades of cast iron was studied. Whilst a satisfactory range of values has been established, unfortunately discrepancies between different machines and the variation in results due to the normal heterogeneity of cast iron have led to a scatter of results which up to the present does not justify final standardisation. A recommended procedure, however, has been evolved and is now in regular use by a number of investigators for a period of time prior to further consideration with a view to its possible ultimate standardisation. Peculiarities of the test on cast iron exist, such as the double-blow effect, whereby the broken part of the specimen shows frequently two or more impressions of the knife-edge. This phenomenon has been studied in detail and the mechanism of the double-blow effect finally established by a high-speed photographic record of the test in progress. Other variables have also been studied with a view to their elimination as possible disturbing factors in the test.

INTRODUCTION.

METALLURGICAL advances in the development and production of iron castings have resulted in substantial improvements in the mechanical properties available and have greatly widened the field of application of cast iron in modern engineering practice. An outstanding deficiency in cast iron has always been its brittleness, but it is generally recognised that the shock resistance of modern castings has improved along with the other mechanical properties. As iron castings are, in both peace and war, being employed under conditions of higher stressing and often in locations where they are subject to shock loading, a demand has arisen for a more definite evaluation of their impact properties. This demand has become more insistent when, owing to shortage of strategic metals in wartime, consideration has been given to the use of cast iron in substitution of such tougher materials as steel or common non-ferrous alloys.

Attempts have been made from time to time in the past to develop

* A Joint Report on work carried out by the Technical Advisory Panel to the Directors for Iron Castings, Iron and Steel Control, Ministry of Supply, and the British Cast Iron Research Association, received October 14, 1944.

† Secretary to the Technical Advisory Panel.

tests suitable for measuring the toughness of cast iron, but such attempts have been fraught with many difficulties and until recently no generally acceptable test has emerged. This paper records an investigation of this problem leading to the development of a test employing the standard Izod machine.

HISTORICAL.—PREVIOUS WORK AND AVAILABLE TEST PROCEDURES.

The literature contains many references to the shock resistance of cast iron and to the development of tests to measure this property. A wide variety of different testing procedures has been considered in the past. A detailed review of these is unnecessary, as many of them are completely unsatisfactory. Briefly, the following tests have been described and were available for consideration at the start of this investigation.

(a) *Tests on Finished Components.*

Tests of this nature have been adopted from time to time in works practice⁽¹⁾ throughout the industry, as, for example, in the testing of chilled car wheels and more recently of cast-iron crankshafts, and usually involve either the dropping of a weight from various heights on to the casting or dropping the casting from a fixed height on to a concrete floor. Such a method is a useful works test for a particular type of casting, but in no way lends itself to standardisation.

(b) *Drop Tests on Test Bars.*

These usually involve a dropping weight or tup striking, at the bottom of its fall, a test bar resting on suitable supports. Some attempts have been made in France and the United States of America⁽²⁾ to standardise suitable procedures.

(c) *Repeated-Impact Tests.*

Work has been carried out on cast iron using a repeated-impact test such as that developed by Stanton. Considerable experience with the Stanton test in the Krupp machine was obtained by the B.C.I.R.A. In this test a grooved round bar was hit on opposite sides alternately by a falling weight actuated by a cam. In general, the test proved unsatisfactory, owing to the fact that its long-term character introduced, in an indeterminate manner, the question of fatigue. Furthermore, the results were extremely erratic and not reproducible.

(d) *Single-Blow Tests.*

Two forms of test used with considerable success for assessing the shock resistance of materials other than cast iron fall under this heading. These are the Charpy and the Izod impact tests, both widely known and requiring no further description here. In Great Britain the Izod impact test is used much more than the Charpy test, the former being the specified standard test for steel.

In 1927, the American Society for Testing Materials appointed a Sub-Committee to investigate the possibility of standardising an impact test for cast iron.⁽³⁾ A wide range of Charpy and Izod test specimens was used and some of their conclusions are pertinent in the present context. It did seem possible that both the Izod and the Charpy impact test could be modified to give suitable testing conditions for cast iron, although small test specimens such as those used for steel and all notched specimens were found to be unsatisfactory for cast iron.

As the Izod is the most popular test in Britain for the impact testing of steels, all the systematic work carried out in this country has been

in the direction of modifying the standard Izod machine to suit the needs of cast iron. The B.C.I.R.A. in 1938 developed an impact test for cast iron which has been used extensively and has proved useful in gaining information on shock resistance. The test was carried out in a standard 120-ft.lb. Izod machine fitted with a special vice to take a bar 0.798 in. in dia., unnotched, with a striking height of 1.3 in. (Fig. 1). The use of this test has been recorded by several investigators.^(4, 5, 6, 7) In this test the forward grip (Fig. 1) was cut away to a depth of 0.25 in. below the upper surface of the back grip, this being on the same level as the top of the vice. This expedient prevented jamming by fracture below the grips.

The values obtained for the 0.798-in. bar with 1.3-in. striking height ranged from about 5 ft.lb. for a phosphoric iron to about 35 ft.lb. for a high-duty alloyed cast iron. The test proved to be not applicable to special cast irons of the austenitic variety nor to malleable irons, in which case the energy required to break this test bar frequently exceeded the capacity of the machine.

This test was used to an increasing extent and was found, within limits, to be reliable and informative. Braidwood^(6, 7) studied high-duty cast iron from the point of view of the information given by this test, but concluded that, whilst the present form of test was of real worth, it could be improved if the values generally obtained were greater and less cramped towards the lower end of the Izod scale. He also observed the double-blow effect and other deficiencies of the test which are dealt with at greater length later in this paper.

At the same time as the 0.798-in. form of test-piece, using a 1.3-in. striking height, was recommended by the B.C.I.R.A., other workers in Britain studied alternative forms of the impact test. The main difference between these alternative forms and that recommended as above lay in the use of a groove machined in the test-piece in order to locate the fracture. In one form of test a bar 1 in. in dia. with a groove 0.05 in. in radius, giving a root diameter of 0.9 in., with a 22-mm. striking height was specified. Typical figures for this test are 10 ft.lb. for a medium-phosphorus iron and 20 ft.lb. for a special-process low-phosphorus cast iron.

Various modifications of this test, using round bars generally about 1 in. in dia. and with grooves to locate the fracture, are known to have been used by other investigators in Britain.

The development of complex impact tests, such as the tension-impact and torsion-impact tests, has been noted, but consideration of these falls outside the scope of the present paper.

FORMATION OF THE IMPACT TEST SUB-COMMITTEE.

At the outbreak of war there was still no generally accepted standard method of carrying out the impact test for cast iron, although, as indicated above, some progress had been made towards the development of a

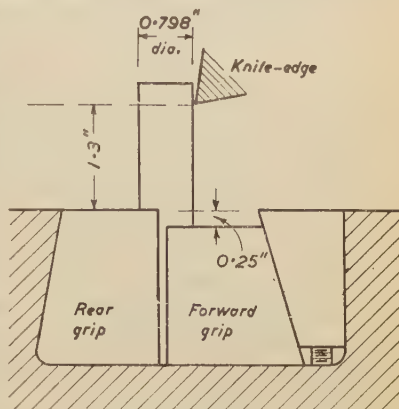


FIG. 1.—Set-Up for British Cast Iron Research Association Test.

generally acceptable test by various bodies interested. The need for more definite information on the impact properties of cast iron was emphasised in the early months of the war, owing, first, to new and severe conditions of service imposed upon iron castings as a result of the war-time use of this material and, secondly, to the need for economy in strategic metals, which in turn led to the adoption of cast iron in place of other materials in shorter supply. Under both these conditions precise information was essential to engineers and designers in assessing the limitations and capabilities of cast iron for specific applications.

Arising from problems raised by some of the Services, the whole question was considered by the Technical Advisory Panel to the Directors for Iron Castings under the Ministry of Supply, and it was decided to set up a Sub-Committee to review the position and, in collaboration with the British Cast Iron Research Association, to consider the further development and possible ultimate standardisation of an impact test.

In considering this problem the Sub-Committee was guided by the following considerations :

(1) The test should be universally applicable for the measurement of the impact strength of cast iron in foundries and engineering laboratories throughout the country. To fulfil this condition, the test should as far as possible utilise existing available equipment, it being out of the question in wartime to consider the large-scale supply of a new form of testing unit.

(2) The limitations imposed by (1), coupled with the results of previous experience, led to the conclusion that the most practical form of test would be one carried out in the standard 120-ft.lb. Izod machine. Further, it was decided that, in order to avoid interference with the normal usage of the machine on steel specimens, the standard striking height of 22 mm. should be maintained, the only modification being in the form of the grips necessary to hold test-pieces of dimensions more suited to the lower impact properties of cast iron.

(3) Previous work has indicated clearly that the standard 10-mm. specimen as used for steel gives results for cast iron too low to be of any practical use. In order to raise the readings given by the Izod machine to a level where a useful distinction is drawn between irons of different qualities, it was felt desirable to use as large a specimen as possible consistent with the proper working of the machine. A large specimen had already been shown to give a useful spread of results.

(4) Test-pieces should be of a form which could be machined from a British Standard test bar as covered by British Standards Nos. 321-1938 and 786-1938.

(5) A sharp notch in the test bar should be avoided, it being felt that this was undesirable in a material of the nature of cast iron.

(6) It was considered at this stage that a groove in the test-piece was desirable in order to locate the fracture and prevent breaking of the specimen in the grips.

T.A.P. FIRST SERIES OF TESTS.

With data from various sources before them and bearing in mind the above considerations, the Sub-Committee felt that the most promising form of test-piece for the initiation of their work was one machined from the standard 1.2-in. dia. bar to give 1.1 in. outside dia. with 3 in. overall length and with a groove of 0.05-in. radius located $1\frac{1}{2}$ in.

from one end of the bar, thus giving a 1.00-in. root dia. The form of this test-piece is shown in Fig. 2.

The use of this test-piece called for the preparation of special dies or grips of the type shown in Fig. 3, which were designed to accommodate the 1.1-in. test bar. It was intended that the centre-line of the groove should be level with the surface of the grips, and for the location of the specimen in the machine either a height gauge as shown in Fig. 2 or a finger gauge as in Fig. 4 was used. In the initial experiments the centre-line of the test-piece was arranged to coincide with the centre-line of the machine. This led to a slight error, in that the knife-edge of the tup struck the specimen before reaching the bottom dead-centre position. A simple calculation showed, however, that the error introduced in this manner was negligible, the striking position being actually 0.0035 in. above the lowest position of the knife-edge.

For the first series of tests a supply of bars in three grades of iron was obtained. Details of these materials are given in Table I. Bars were supplied to seven investigators, who made their own arrangements

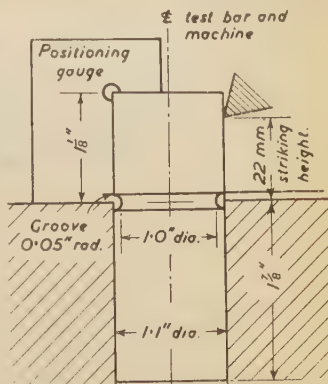


FIG. 2.—T.A.P. First Test-Piece.

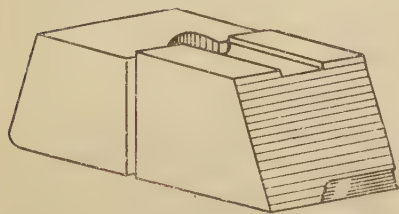


FIG. 3.—Dies or Grips for 1.1-in. Bar.

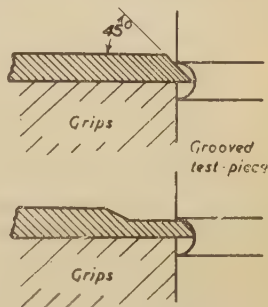


FIG. 4.—Finger Gauges for Grooved Bar.

for machining the test-pieces. For convenience, grips for this size of bar were passed from one investigator to another as necessary. This point should be borne in mind in studying the results, since it was found

TABLE I.—Materials for First T.A.P. Series of Tests.

Material.	T.C. %.	G.C. %.	C.C. %.	Si. %.	Mn. %.	S. %.	P. %.	Ni. %.	Mo. %.	Tensile Strength. Tons per sq. in.	Trans- verse Rupture Stress. Tons per sq. in.	Brinell Hard- ness Number.
A	2.63	1.78	0.85	2.85	1.31	0.09	0.11	2.14	0.94	31.0	47.2	342
B	3.33	2.44	0.89	1.40	0.80	0.06	0.17	...	...	17.8	36.3	225
C	3.25	2.54	0.71	2.66	0.53	0.05	1.27	...	...	10.0	21.5	212

that individual machines showed minor variations which in point of fact rendered it ultimately necessary for the grips to be fitted individually to each machine.

The results obtained by the seven investigators are summarised in Fig. 5. These data were obtained by machining six separate test-pieces from each bar supplied.

A study of the results reveals that investigator *C* recorded much higher figures than the others on the two higher-strength materials. Investigator *G* likewise reported high figures, but the remainder showed some measure of agreement amongst themselves. This agreement is seen to be much closer for the lower-strength material than for the high-duty cast iron. Fig. 5 brings out also the wide variation in results obtained by

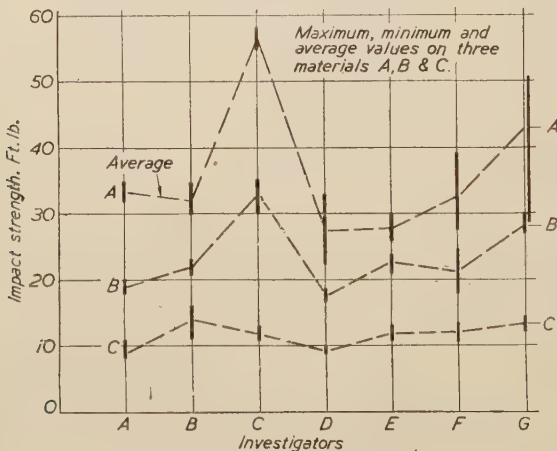


FIG. 5.—First T.A.P. Series of Tests.

some of the investigators, particularly for the higher-strength iron. The very wide spread for material *A* recorded by investigator *G* is particularly noteworthy.

All investigators reported the presence of a second indentation on the same side of the broken-off portion of the test-piece as that which suffered the original blow from the knife-edge. This double-blow effect has been found to be general in the tests on cast iron and, as reported later in this paper, has been the subject of detailed study.

In summarising this first investigation the Sub-Committee reported that the results for some of the materials showed amongst themselves a wide variation, this being as much as 50% for the high-strength iron, although less for the medium-strength iron; on the low-strength material, however, the results were moderately consistent.

All the investigators reported the double-blow effect, and it was felt at that time that this indicated some interference with the free swing of the tup and might possibly be an explanation of the wide variations recorded.

It was the final conclusion of the Sub-Committee, therefore, that the test carried out under the conditions specified was not satisfactory, although there was an indication of agreement sufficiently strong to justify the further study of the test with a view to endeavouring to establish conditions giving more consistent results.

ALTERNATIVE FORMS OF TEST-PIECE.

Several of the investigators had already had experience with different forms of test-piece which had demonstrated varying degrees of consistency in the impact test. It was decided, therefore, at this stage of the investigation to consider alternative forms of test-piece.

The wide variation of results shown in the first T.A.P. series of tests, not only amongst different investigators but even in some cases in one machine, led the Sub-Committee to look for some explanation for the discrepancies recorded. At this time the most obvious possible source of error lay in the double-blow effect, since, although the mechanism by which the double blow occurred was not understood, the second impression (Fig. 12) on many of the test-pieces was of such a nature as to suggest that a considerable expenditure of energy had taken place.

Evidence, however, had come to hand that on some special dead-annealed ferritic cast irons severe jamming of the broken part of the test-piece had taken place and in one example recorded had stopped the pendulum completely.

It was only logical, therefore, in selecting modified forms of test-piece to bear in mind primarily the elimination of the double-blow effect. This was attempted by :

(a) Experimenting with smaller sizes of test-piece so as to allow greater clearances between the broken part of the test-piece and the tup on the one hand and the anvil on the other.

(b) Machining away that part of the test-piece which was known generally to receive the second blow.

(c) Experimenting with notches of such a form as to speed up the fracture of the test-piece, it being hoped that this would affect the relative velocities of the broken part of the specimen and the tup, so enabling the specimen to clear itself more rapidly.

One investigator tried a large number of forms of test-piece, some examples of which are shown in Fig. 6. It will be recognised that these, besides covering various sizes of test-piece, include both grooves and notches for locating the position of fracture, whilst forms such

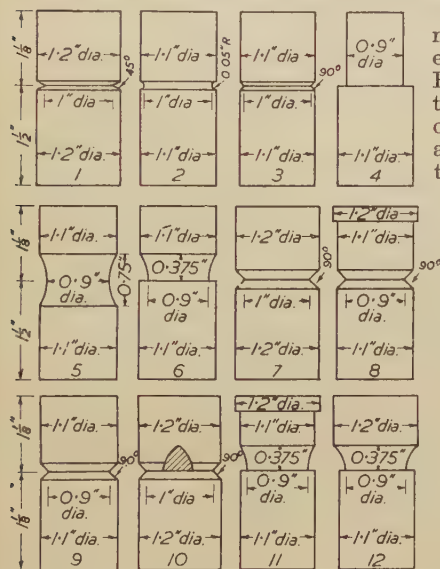


FIG. 6.—Series of Test-Pieces Tried by One Investigator.

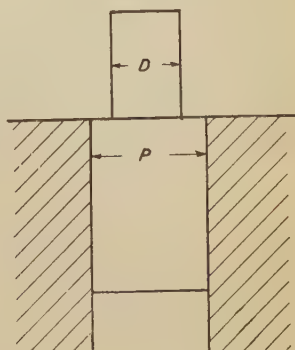


FIG. 7.—Special Test-Piece.

as those shown as Nos. 5, 6, 10, 11 and 12 are all designed to avoid the double blow by the particular shaping applied to the head of the specimen.

The B.C.I.R.A. experimented with a form of test-piece shown in Fig. 7, in which various ratios of the diameters P and D were used. This test-piece was designed to locate accurately the plane of fracture and to give an indication of the maximum diameter which could be allowed for the top part without encountering the double-blow effect. Other investigators experimented independently with various forms of grooves and notches.

It is sufficient for the purpose of this paper to record that, whilst the test-pieces Nos. 10 and 12 in Fig. 6 gave promising results in respect of the elimination of the double blow, none of the various test-pieces tried out proved really satisfactory in giving consistent results. Experience with these different forms of bar confirmed earlier experience that a notch was not satisfactory with cast iron.

About this time evidence came to hand that the double-blow effect sometimes occurred even with steels and non-ferrous alloys, using the 10-mm. square or standard round specimen. The phenomenon, however, always seemed to be associated with the low impact values recorded for brittle materials.

T.A.P. SECOND SERIES OF TESTS.

As the experimental work on alternative forms of test-piece was inconclusive in leading to consistent results and in eliminating the double-blow effect, it was felt that another possible source of error in the first series of tests lay in a variation in the fit of the grips or dies in the various machines, it being recalled that, on account of the special size of test bar employed, namely, 1.1 in. in dia., only two sets of grips were available and were passed from one investigator to another.

At the same time it was realised that a number of firms acting in co-operation with the B.C.I.R.A. had had considerable experience with the 0.798-in. plain test bar with the grips cut away as indicated in Fig. 1, using a striking height of 1.3 in. Although the results of this test had not been such as to justify its consideration for immediate adoption as a standard, there appeared to be a greater consistency in the results than was obtained in the T.A.P. first series. It was therefore agreed that for the second series of tests the B.C.I.R.A. form should be employed, but with the standard striking height of the Izod machine, namely, 22 mm. A standard material of about 18 tons per sq. in. tensile strength was distributed to six investigators. Each investigator was asked to keep a careful record of all details of the test, including striking height and fit of grips, and to note points such as the condition of the knife-edge. Six test-pieces, 0.798 in. in dia. and 3 in. long, were machined from each 1.2-in. dia. \times 21-in. bar and the grips were as shown in Fig. 1. Most of the investigators were already equipped with grips fitted to their machine. The results obtained by the six investigators are illustrated in Fig. 8.

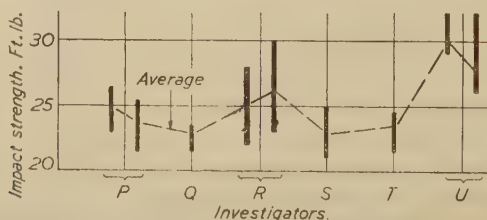


FIG. 8.—Second T.A.P. Series of Tests.

Some measure of consistency is seen among the results, apart from the figures provided by investigator *U*, although the spread of results recorded by each investigator and the overall spread was felt still to be wider than was desired or acceptable in a test for standardisation. Further work was therefore undertaken on details of the test.

POSSIBLE ERRORS IN THE IMPACT TEST.

In the further study of variations found in the impact test, full consideration was given to the following points :

- (a) The use of a long bar subjected to repeated tests as against individual test-pieces.
 - (b) The influence of previous stressing on the bar used for the impact test, *i.e.*, whether the use of material previously broken in transverse is undesirable.
 - (c) The double-blow effect.
 - (d) Errors introduced by inaccuracies in the size of test-piece and the fit of the grips.
 - (e) Machine factors, including the general condition of the machine, the set of the knife-edge, the rigidity of the recording mechanism, &c.
- (a) *Use of a Long Bar Subjected to Repeated Tests as Against Individual Test-Pieces.*

It is, of course, well known that the standard specimen of the Izod test on steel carries three notches (B.S. 131-1933), so that on one specimen actually three results are obtained by raising the specimen progressively to three positions. In the case of cast iron it was felt that there would be some advantage in obtaining a larger number of results by carrying out successive tests on a long bar rather than by cutting the bar into 3-in. lengths for separate test-pieces. Generally speaking, from a given length of bar much double the number of results can be obtained by this method.

In the first series of T.A.P. tests, the B.C.I.R.A., following this line, adopted the method of machining the 0.05-in. groove at spaces of $1\frac{1}{8}$ in. along the length of the bar. The hole normally provided in the base of the Izod machine for accommodating the 10-mm. steel specimens was enlarged to pass the 1.1-in. dia. bar, and provision was also made for the accommodation of this bar in the foundation. Testing of this bar was carried out as shown in Fig. 9. Location of the bar for each test was achieved by means of a positioning gauge as shown in Fig. 4.

Full details of the results obtained in this way on materials *A*, *B* and *C* employed in the first series of tests are given in Table II. The figures for materials *A* and *B* call for no special comment, but in those for the weakest material *C* a remarkable alternation of high and low figures will be noted, which supports the suggestion that some weakening or damage to the bar held in the grips occurred at each test, the effect being substantial when the highest result was recorded but being apparently negligible when on the next test the material was already weakened and broke at a low figure. It would appear, therefore, that this irregularity condemns the principle of using a long bar when carrying out 1.1-in.

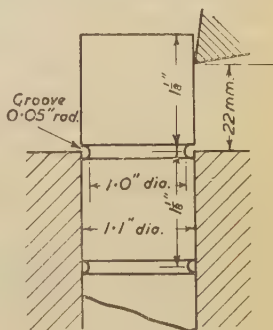


FIG. 9.—Repeated Tests on Long Bar.

groove tests on a weak material. It is very noticeable, however, that a similar effect is not recorded in any measure on the stronger materials.

TABLE II.—*Long-Bar Results on First Series of Tests.*

Material A.		Material B.		Material C.	
Impact Strength. Ft.lb.	Double-Blow Distance. In.	Impact Strength. Ft.lb.	Double-Blow Distance. In.	Impact Strength. Ft.lb.	Double-Blow Distance. In.
32.5	None	18.5	None	13.0	0.5
30.0	0.8	24.5	0.75	2.5	0.35
39.5	None	19.5	None	13.5	0.6
33.0	None	23.0	0.7	2.5	0.35
32.0	None	21.5	0.65	12.5	0.6
28.0	0.55	20.5	0.6	3.0	0.45
				11.0	0.5, 0.6, 0.65 (Triple)
Av. 32.5		Av. 21.3		Av. (discarding low values) 12.5	

Some work was subsequently put in hand to obtain further evidence with regard to this phenomenon. Two 21-in. transverse bars in a cast iron giving an impact value in the region of 25–30 ft.lb. were machined to 0.798 in. in dia., the test in this case corresponding to that used in series 2 in which no groove was employed. The top part of one bar was tested in one length, six impact tests being obtained, and the bottom was cut into three separate pieces 3 in. long. On the second test bar the top part was cut into three pieces and the bottom part left as a long bar. The results are given in Table III.

TABLE III.—*Comparison of Long-Bar and Single Tests.*

Bar No.	Half of Transverse Bar.	Form of Test-Piece	Impact Values. Ft.lb.						
			Individual.						Average.
1	Top	9-in. bar	18	19	19	19	18	21	19
1	Bottom	3-in. pieces	19	19	19	...	...	...	19
2	Bottom	9-in. bar	19	22	20	19	20	20	20
2	Top	3-in. pieces	21	22	21	...	...	...	21.3

As these results were obtained on two bars only, a further group of tests was carried out in which two sets of bars were prepared from one ladle of metal. No transverse testing was carried out on these bars, but half the available material was machined to 0.798 in. in dia. for the entire length and was tested in this form, whilst the other half of the material was tested in the form of 3-in. lengths. Specimens were marked to show whether they came from the top, centre or bottom of each bar. The results are presented in Table IV.

The average final values are slightly higher for the bars tested in 3-in. lengths. However, the difference is not marked and is well within the range of figures obtained on any one bar. There is, however, no repetition of the periodic weakening of material held in the grips. An analysis of this and a large number of similar cases shows, therefore, that, in spite of the evidence obtained on bar C in the first series of tests, there is, generally speaking, no evidence that the use of a long bar broken repeatedly

TABLE IV.—Further Comparison of Long-Bar and Single Tests.

Specimens.		Impact Values. Ft.lb.											
		Top.			Centre.					Bottom.		Averages.	
First Set of Bars.													
Long bars	1 .	27.5	29.0	23.0	25.0	23.5	30.0	28.0	28.0	27.0	29.0	27.5	26.9
	2 .	26.0	29.0*	28.0	28.0	23.0	23.0	26.0	27.0	28.0	...	26.9	
	3 .	29.0	26.0	29.0	24.5	27.0	26.0	29.5	29.5	30.0	...	27.8	
	4 .	24.5	25.0	27.0	25.5	...	...	...	...	...	...	25.5
3-in. pieces	5 .	30.5	15.0†	27.5	29.0	...	29.0	28.2
	6 .	27.0	...	...	23.5	26.5	...	...	...	27.0	...	26.0
	7 .	31.0	...	...	28.5	28.0	...	...	...	32.0	...	29.9
	8 .	29.0	...	...	29.5	25.0	...	...	27.5	28.0	...	27.8
Second Set of Bars.													
Long bars	1 .	28.0	29.0	29.0	30.0	32.0	29.0	27.0	27.0	29.0	...	28.9	29.2
	2 .	29.5	29.5	28.0	25.0	28.0	31.0	31.0	31.5	32.0	...	29.5	
3-in. pieces	3 .	28.0	28.0	30.0	29.0	...	28.8	30.8
	4 .	33.0	...	...	32.0	33.0	...	...	...	33.0	...	32.8

* Double Fracture.

† Flaw.

is undesirable. This is an important practical point, as the testing of the long bar enables more results to be obtained from a given length than when several 3-in. lengths are used in each test. As already indicated, however, the method calls for some minor modification of the Izod machine to accommodate the larger specimens as used for cast iron.

(b) *The Influence of Previous Work on the Bar Used for the Impact Test.*

The view was expressed by some members of the Sub-Committee that when the transverse test was carried out on the 21-in. bar this test might have some effect in weakening the material and thus lead to lower results in the impact test subsequently carried out than would be recorded if the material had not previously been strained. Since cast iron undergoes a considerable plastic as well as elastic deformation in the transverse test, the bar between the centres will take up a permanent set according to the magnitude of the stress imposed, this plastic set being greatest at the centre of the transverse bar, where the stress is greatest. Further, the plastic deformation is coincident with the direction of loading, so that in a subsequent impact test the result obtained might be influenced by the position of the test-piece in relation to the previous transverse loading.

A number of experiments were, therefore, carried out, keeping this theory in mind. These experiments indicated that any variations caused by prior transverse testing were well within the limits of variation in the test, and any possible effect in the direction of the impact blow in relation to the direction of prior bending could not be detected. This conclusion is in line with experience of many investigators who have recorded results on unstressed bars as well as on bars previously tested in transverse. No influence of the previous transverse stressing could be detected in the figures ultimately obtained.

(c) *The Double-Blow Effect.*

Reference has already been made to the double-blow effect, the evidence of which is seen on many cast-iron test-pieces after the impact test. The general appearance of a broken test-piece is as shown in Fig. 12. Near the top of the test-piece a marked impression is made where the knife-edge of the tup delivers the main blow; nearer the fracture a second

impression somewhat smaller than the first is also made on the test-piece, and from the depth of this impression it is evident that it has been made with considerable force.

Various modifications of the double-blow effect occur. Thus, in some cases it has been found that multiple impressions occur on the test-piece. Sometimes two or three secondary impressions diminishing in depth are seen. Generally speaking, the second impression or group of impressions lies directly below the main impression, but in other cases, where there has been evidence of the specimen leaving the machine with a twist on it, the secondary impression has been found slightly offset to one side or the other.

Some variation has been noted in the distance between the two impressions on any one type of cast-iron bar, and it has been established that under given conditions the stronger the material the wider is the spacing between the impressions, so that in some cases with high-duty cast irons the secondary impression is sometimes found very close to the line of fracture.

The double-blow effect has been recorded on all types and sizes of test-piece. It was at first thought that the effect was confined to the larger diameters of test specimens, with or without grooves or notches to locate the fracture. Further experience has shown, however, that the double-blow effect is, as far as can be judged, just as prevalent with the 0.798-in. dia. test-piece as with the 1.1-in. size of bar. As already mentioned, the double-blow effect has also been noted on 10-mm. bars in both some non-ferrous alloys and steels giving a relatively low impact value. It is evident, therefore, that the double-blow effect is not directly a function of the size of test-piece.

It was felt that the double-blow effect called for further investigation, more especially as it was suspected of introducing a serious source of error in the test results.

In the first place, careful examination was made of a number of machines in which tests on cast iron had been carried out. It was found that there were indentations and signs of wear, both on the top surface of the vice and on the underside of the tup. It is clear, however, that the secondary blow on the test-piece was delivered by a sharp edge, and it was concluded, therefore, that the marks on the tup and anvil, whilst giving some idea of the movement of the test-piece after fracture, do not themselves represent any feature which could be associated with the double blow.

In an endeavour to determine more accurately the behaviour of the test-piece after fracture a number of tests were carried out, using coloured paints on the knife-edge, under surface of the tup and on the anvil, so that by examination of the specimen after fracture it could be seen where the paint surfaces had been damaged and by the paint picked up on the test-piece its course could be traced.

The main conclusion from this section of the work was that the suspicion that the double blow was caused by the knife-edge itself was confirmed, but the exact mechanism whereby the specimen received the double blow from the knife was still not clearly understood.

In view of the marks showing contact between the test-piece and the top of the vice and underside of the tup, experiments were carried out by various workers to modify the shape of these parts with a view to eliminating the double-blow effect. One such effort is shown in Figs. 10 and 11, which illustrate, first, the standard anvil and grip arrangement and, secondly, a modified vice and grips in which any bouncing tendency, whereby the specimen would bounce up from the surface of the vice to hit the knife-edge a second time, is eliminated by the cutting-away of



FIG. 10.—Standard Anvil Set-Up.



FIG. 11.—Clearance Anvil.

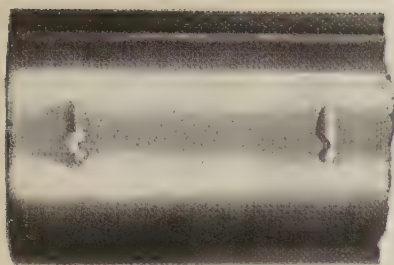


FIG. 13.—Double-Blow Mark, showing impression of nick in knife-edge.

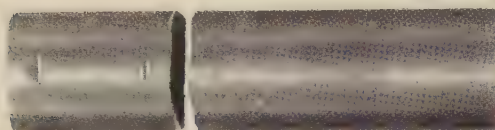


FIG. 12.—Typical Double-Blow Effect.



FIG. 14.—Knife Insert, showing defect in edge.

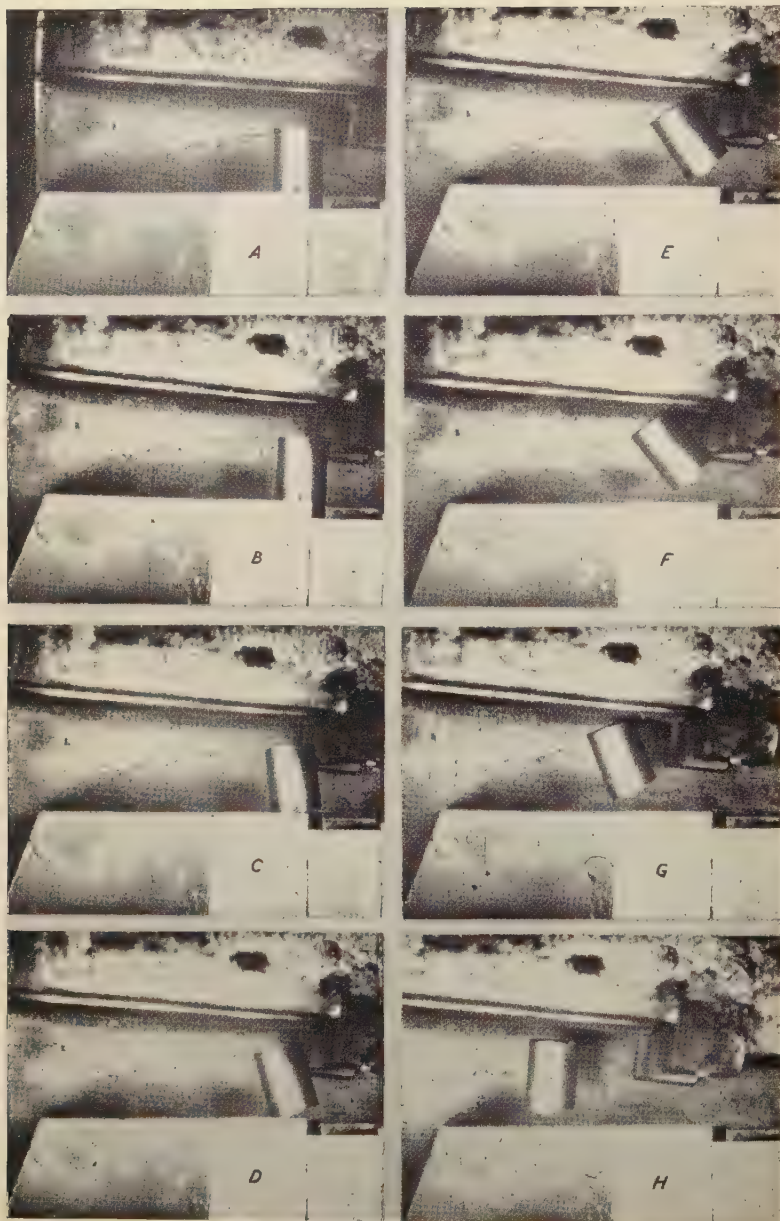
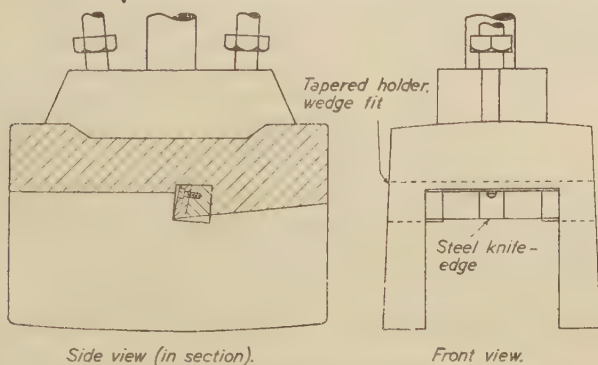


FIG. 15.—Sequence of Eight Exposures, showing the behaviour of a 0.798-in. unnotched cast-iron impact test-piece on fracture.

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the vice. Neither this nor experiments with modified tup arrangements and reduced energy of blow were successful in eliminating the double blow.

Some interesting data on the double-blow effect came to light accidentally during the course of these experiments. A cast-iron test-piece showing a marked double-blow effect as indicated in Fig. 13 was noted to show a peculiarity in both the main impact and the secondary blows which clearly corresponded to some defect in the knife-edge. The knife-edge in question is shown in Fig. 14, in which it is seen that a chip has been broken from the striking edge. The location of the knife insert in the tup is shown in Fig. 16. A careful study of the shape of the knife-



Side view (in section). Front view.
Hardened steel knife-edge is fixed into tapered holder before insertion in tup

FIG. 16.—Position of Knife Insert in Tup.

edge and of the indentations showed that the secondary blow was formed by the test-piece hitting the underside of the knife-edge with considerable force after fracture was complete.

With all the evidence now available it was suggested that the mechanism of formation of the double blow and the behaviour of the test-piece after fracture were somewhat as shown in Fig. 17.

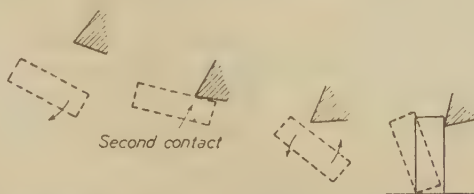


FIG. 17.—Suggested Explanation of the Occurrence of the Double Blow.

If this conclusion is correct it confirms that the second blow does not bear any relation to the indentations on the top surface of the vice. Most probably the action of the double blow takes place in a fraction of a second after fracture, and, whilst the energy of the double blow is undoubtedly great, as indicated by the depth of the impression, the movement of the test-piece seems to be such that the main energy of this blow is at right angles to the line of travel of the tup and no interference with its free swing is encountered. This is in line with experience in the tests carried out on various forms of test-piece which show that there is no

relationship between the double-blow effect and the impact-strength value. Thus, in some cases two specimens of the same material have shown a higher impact strength where a double blow has been recorded than in a test without this effect, whereas in other examples exactly the reverse has been found.

An interesting experiment was carried out by the B.C.I.R.A. in which a special stirrup and wire-loop arrangement as shown in Fig. 18 was used

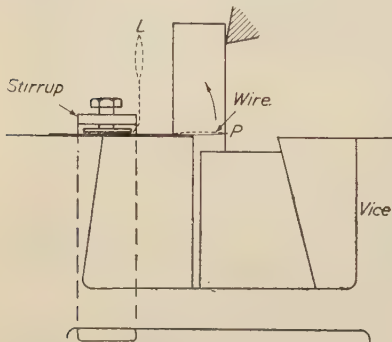


FIG. 18.—Arrangement to Restrict Movement of Test-Piece after Fracture.

to check the movement of the broken part of the test-piece after fracture. Fracture occurred below the wire in the usual manner, but the path of the lower end of the broken piece was restricted to the arc made by the wire. It was found in practice that the test-piece left the loop of wire in such a position as shown at L in Fig. 18. This arrangement was effective in eliminating the double blow at will.

Five transverse bars of different kinds of cupola and alloy iron were machined to 0.798-in. dia. unnotched bars, which were broken with the old standard striking height of 1.3 in.

On alternate breaks the double blow was eliminated as described above. The impact figures obtained are given in Table V.

TABLE V.—Effect of Double Blow on Izod Figure.

Material.	Impact Value. Ft.lb.					Tensile Strength. Tons per sq. in.	
	Double Blow.		No Double Blow.		Increase Due to Double Blow.		
<i>A</i>	17.0	18.0	16.5	17.0	15.5	1.2	22.8
	Average 17.5			Average 16.3			
<i>B</i>	21.0	19.0		19.0	19.0	1.0	22.5
	Average 20.0			Average 19.0			
<i>G236</i>	4.0	7.0 *		3.0	5.0	0	11.7
	Average 4.0			Average 4.0			
<i>G237</i>	13.0	14.0		14.5	13.5	—0.5	20.8
	Average 13.5			Average 14.0			
<i>G238</i>	19.5	18.0		16.0	18.5	1.5	21.3
	Average 18.75			Average 17.25			

* Jamming.

There seems to be some evidence that when the double blow has occurred the average energy of impact is slightly greater than when the effect is restricted; on the other hand, in one case the amount of energy recorded with the double blow was actually less. It is concluded, therefore, that, bearing in mind the heterogeneity of cast iron and the inconsistency which can be expected from any mechanical tests on it, it is safe to neglect the presence of the double blow completely on this evidence.

A number of test-pieces have been tried out by various investigators in an endeavour to eliminate the double-blow effect. Examples are given

in Figs. 6 and 7, showing test-pieces so designed that the metal at the point of double blow has been removed, thus avoiding this source of possible error. Experience with these and a number of similar test-pieces has, however, been neither conclusive nor satisfactory, and attempts to avoid the double blow by such modifications in the test-pieces have now been abandoned.

The opportunity of having a high-speed camera record of the impact test in progress has provided confirmation of the above views with regard to the double blow. In order to provide a view of the fracture of an impact test-piece, a special tup was made with the side cut away. The tup was balanced with lead to produce a symmetrical blow and to maintain the standard striking energy of 120 ft.lb. An Eastman high-speed camera making up to 3000 exposures per sec. on 16-mm. film was used. A number of shots were taken of the test in progress on both 0.798-in. unnotched and 1.1-in. grooved test-pieces and, as a matter of interest and for comparison, also on three 0.45-in. notched steel test-pieces of various impact properties.

Fig. 15 shows a sequence of photographs, from which it is seen that immediately after fracture the top part of the test-piece flies upwards and forwards and the lower part of this piece strikes the underside of the knife-edge before being thrown clear. Fig. 15(a) shows the knife-edge approaching a 0.798-in. unnotched bar and in Fig. 15(b) the knife-edge is just touching the test-piece. Figs. 15 (b) to (d) and again (e) and (f) are consecutive frames on the film and show the exact motion of the broken-off portion as it flies up and hits the knife-edge a second time. Whether or not the test-piece struck the underside of the tup cannot definitely be deduced from these photographs, but examination of the pieces indicated that contact had taken place in some tests.

The 1.1-in. grooved bar moved after fracture in a similar manner to the 0.798-in. bar, but the upper edge of the test-piece struck the underside of the tup before a double blow could occur. The test-piece then continued its horizontal motion away from the knife-edge, so that no secondary contact took place between the knife-edge and the test-piece. In Figs. 15 (g) and (h) the specimen is somersaulting in a clock-wise direction away from the machine.

It is interesting to record the speed at which the fracture of cast iron takes place and to compare it with the fracturing of a ductile steel. The frames represented by Figs. 15 (b) and (c) were separated by an interval of less than $\frac{1}{20000}$ th of a second and yet during this period a crack had apparently formed and the test-piece was broken into separate pieces. The mild-steel test-piece, on the other hand, was seen to bend and shear at the notch before the propagation of the crack across the section.

(d) *Errors Introduced by Inaccuracies in the Size of Test-Piece and the Fit of the Grips.*

Emphasis has previously been laid on the possibility that the variation recorded between different investigators in the first series of tests may be due to errors introduced by passing grips from one investigator to another, with the result that a perfect fit of the grips to each machine could not be guaranteed. A further possible error was felt to arise from the condition of the grips—that is to say, whether the top edge across which the specimen is broken is sharp or worn—and, again, errors might be introduced by inaccuracies in machining the test bars.

One investigator obtained reasonable consistency in the impact test by using a V-shaped grip which supported the specimen at two points only in the rear grip, the test bar being unmachined. Subsequent experience showed, however, that, whilst this method had the advantage of eliminat-

ing machining time, it is not to be recommended as general practice. Tests carried out, however, on bars deliberately machined within the range 0.794–0.802 in. showed that the average impact value was reasonably consistent, varying as shown in Table VI. The degree of consistency is surprising, since it was thought that the fit of the test bar in the grips would be vital. In spite of this result, however, it is felt that the machining tolerance should not be greater than ± 0.001 in. on the correct diameter.

TABLE VI.—*Effect of "Off Size" Bars in the Izod Test.*

Position of Test-Piece in Bar.	Machined Diameter. In.	Average Impact Value. Ft.lb.	Position of Test-Piece in Bar.	Machined Diameter. In.	Average Impact Value. Ft.lb.
Bottom half	0.794	17.1	Top half	0.798	18.9
" "	0.796	16.7	" "	0.800	17.2
" "	0.798	16.6	" "	0.802	17.6

(e) *Machine Factors, Including the General Condition of the Machine, the Set of the Knife-Edge, the Rigidity of the Recording Mechanism, &c.*

During the course of the tests in series 1 and 2 various minor points were noticed in the testing machines. Special note was taken of these, as it was felt that they might have some bearing on the results recorded in these series of tests. Thus, in some cases it was found that the Izod machine was not mounted in accordance with B.S. 131-1933 on a heavy concrete block, although the rigid fixing of the machine is considered essential in order to obtain consistent results.

The condition of the knife-edge was often found to be far from satisfactory, although it is not known to what extent any wear and tear of the knife-edge may affect the result, provided that the mean striking height is reasonably correct. In some cases also erratic results were recorded as a result of slackness in the recording mechanism. The remedy in this case is, of course, obvious. In the continuation of this work, therefore, special attention was drawn to the condition of the machine, and special recommendations were made to investigators to check the following :

- (1) Actual striking height.
- (2) Fit of grips.
- (3) Condition of the grips, especially any signs of wear on the back edge.
- (4) Condition of the knife-edge.
- (5) Rigidity of the foundation on which the machine is mounted.
- (6) Assurance of the correct capacity of 120 ft.lb.
- (7) Positioning of the vice with respect to the pendulum, so that the knife-edge just touches the specimen at bottom dead-centre. The scale should then register 120 ft.lb.
- (8) Slackness of the pointer recording mechanism.

T.A.P. THIRD SERIES OF TESTS.

At this stage of the work the assistance of the makers of the Izod machines was enlisted, and it was agreed that before any further work was carried out all the machines in question should be inspected and overhauled, particular attention being given to the points mentioned above.

While the machines were being inspected and prepared for further check tests, more detailed attention was given to the final selection of the form of test-piece for what was hoped would be the last series of tests before making recommendations for standardisation.

In this connection the B.C.I.R.A. had at intervals during this investigation developed a number of forms of test-piece which were designed either to avoid the double-blow effect or to give the maximum spread of results with irons of different grades. The B.C.I.R.A. summarised their work in this connection by carrying out tests using the different forms of test-piece for the determination of impact-strength figures on six grades of iron. The chemical analyses and mechanical properties of these six irons are given in Table VII. The details of the different test-pieces

TABLE VII.—*Chemical Analyses and Mechanical Properties of Six Grades of Cast Iron used in B.C.I.R.A. Tests.*

Melt No.	T.C. %	C.C. %	G.C. %	Si. %	Mn. %	S. %	P. %	Cu. %	Cr. %	Ni. %	Mo. %	Transverse Rupture Stress. Tons per sq. in.	Tensile Strength. Tons per sq. in.	Brinell Hardness Number, 3000/10.
G164	3.29	1.22	2.07	2.39	1.42	0.056	0.95	...	...	...	...	19.1	10.0	242
G165	3.14	0.93	2.21	1.85	0.83	0.065	0.057	...	...	...	...	27.4	15.2	215
G170	3.20	0.92	2.28	2.34	0.79	0.031	0.037	...	...	...	...	33.8	18.1	209
G171	2.66	1.02	1.54	1.95	0.72	0.036	0.036	...	...	...	...	42.0	25.1	242
G172	3.00	1.16	1.84	2.19	0.76	0.038	0.032	1.52	0.46	...	0.98	53.1	26.9*	315*
M495	3.15	0.83	2.32	2.11	0.78	0.052	0.089	...	...	1.96	0.83	46.6†	27.6†	282†

* After heat treatment for 10 hr. at 550° C.

† After heat treatment for 5 hr. at 320° C.

(The corresponding impact-test specimens were given the same heat treatment.)

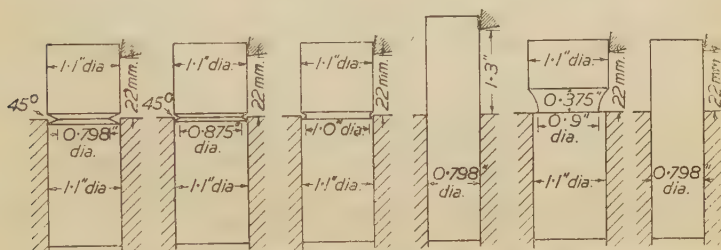


FIG. 19.—Test-Pieces Used in British Cast Iron Research Association Tests on Six Grades of Cast Iron.

used are shown in Fig. 19 and the results of this work are summarised in Fig. 20.

The results of this B.C.I.R.A. investigation confirmed the general trend of the T.A.P. Impact Test Sub-Committee's findings that the most promising results are shown by the 1.1-in. grooved bar which was first selected for investigation by the Sub-Committee and the 0.798-in. plain bar which with the different striking height had been selected in the first place by the B.C.I.R.A. as giving the most uniform results. It was therefore agreed that in the T.A.P. third series of tests, after the machines had been checked, repeat tests should be made with these two types of bar.

A number of test bars 1.2 in. in dia. were prepared in an iron with a tensile strength of about 25 tons per sq. in. These were distributed to seven investigators for tests after the machines had been checked. In most cases the investigators prepared grips that were accurately fitted to the machines. In a few cases, however, grips were passed from one

investigator to another, but in these cases special attention was given to the rigid fitting of the grips in the machines.

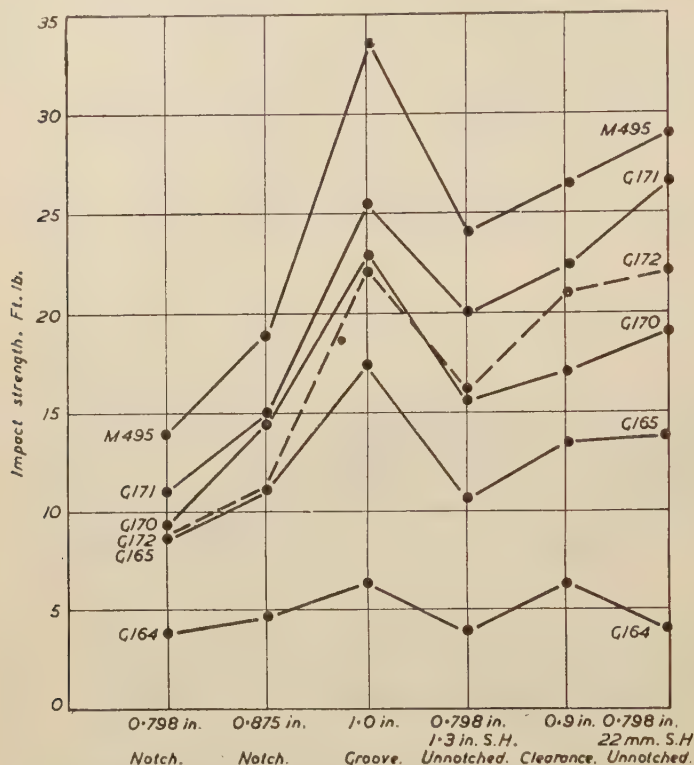


FIG. 20.—Test Results on Six Grades of Cast Iron Using Forms of Test-Piece as shown in Fig. 19. (S.H. = striking height.)

The results of this third series of tests, using the 1.1-in. grooved bar and the 0.798-in. plain bar, are summarised in Fig. 21.

A study of these results shows that still very erratic results were obtained by some investigators, but, on the whole, there was a greater tendency towards uniformity than had been obtained previously. The conclusions which the T.A.P. Sub-Committee drew from these tests were as follows :

(a) The results still showed too wide a dispersion to justify the immediate standardisation of either form of test-piece.

(b) The 0.798-in. plain bar gave more consistent results than the 1.1-in. grooved bar.

(c) No explanation can be offered for the very divergent results obtained by certain investigators, as, for example, *T* on the 1.1-in. grooved bar, but it will be noted that there is still a tendency for certain machines, as, for example, those of *S* and *V*, to give high readings with both forms of test.

After reviewing all the results available to date, however, the Sub-Committee felt that the results, whilst not sufficiently satisfactory to

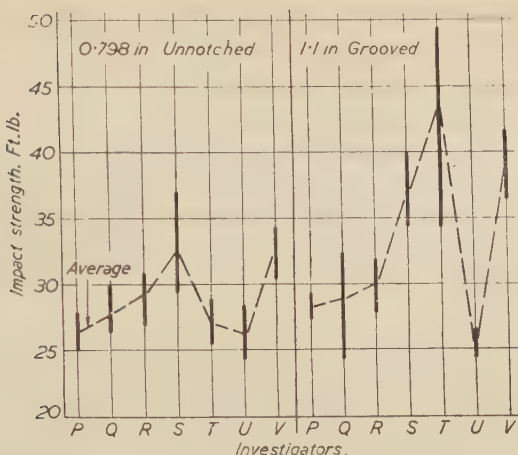


FIG. 21.—Third T.A.P. Series of Tests.

justify any attempt at standardisation, were of a nature to encourage a continuation of the work. There seemed now ample evidence to show that the most promising line to follow was the use of the 0.798-in. plain bar with 22-mm. striking height, and with the form of grips previously developed by the B.C.I.R.A. to avoid any tendency to jam or fracture below the top surface. The Technical Advisory Panel therefore decided to ask the co-operation of the industry in adopting a test on these lines for general use over a period, after which the question of standardisation could again be reviewed. For this purpose a recommended procedure for carrying out the Izod impact test on cast iron was prepared and published.⁽⁸⁾

RECOMMENDED PROCEDURE FOR THE IMPACT TEST FOR CAST IRON.

(a) Details of the Test.

The dimensions of the test-piece and arrangement of the grips in the

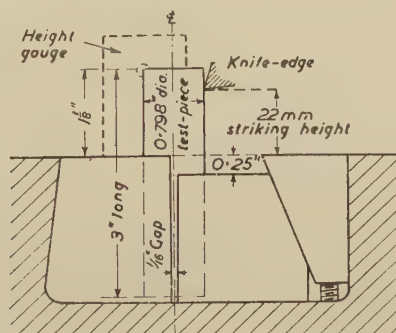


FIG. 22.—Set-Up for Recommended Test.

Izod machine are shown in Fig. 22. The details for carrying out the test according to the procedure recommended are as follows :

(1) The impact test should be carried out in the standard 120-ft.lb. Izod impact machine.

(2) The form of test-piece is to be a 0.798-in. dia. (0.5 sq. in. cross-sectional area) plain bar, with no notch or groove. A separate test-piece to be employed for each test.

(3) The test-piece is to be held in grips or dies in accordance with Fig. 22. This, it may be noted, is, with minor modifications, in line with the practice developed and recommended by the British Cast Iron Research Association following their own study of this problem in 1937. In the sketch showing the general arrangements for the test for cast iron, the grips should be so dimensioned that when the test-piece is in position the knife-edge is just touching it when the tup is hanging in bottom dead-centre position. This position must be found for each machine.

(4) A striking height of 22 mm. is to be employed, this height to be measured from the top of the rear grip, as indicated in Fig. 22.

(5) Special attention must be given to the fit of the grips in the machine and the fit of the specimens in the grips. This calls for care in finishing the specimen accurately to diameter, with a smooth machined or ground surface.

(6) Wherever possible, at least three tests on any one material should be taken and averaged.

(7) Test-pieces may conveniently be machined from the 1.2-in. dia. \times 21-in. long transverse test bar or, alternatively, from the broken halves of this bar after transverse testing. In taking test-pieces, clearly the top end of vertically cast bars should, if possible, be avoided.

(b) *Test Results.*

During the trial period in which the test is being used by a number of firms, data are being accumulated relating the impact test with tensile and other properties. Check tests are also being carried out from time to time by firms following the recommended procedure on material of standard quality distributed by the Technical Advisory Panel and the B.C.I.R.A. It is intended that by this means individual manufacturers will obtain an extensive experience of working the test, and the general application of the results will be established by the check tests as indicated.

CONCLUSION.

An extensive study has been made of a means of measuring the impact strength or toughness of cast iron. The Izod machine was selected as the most suitable equipment for conducting the impact test, owing to its general availability in foundries and engineering establishments. A number of forms of test-piece was tried out with a view to determining the best form to give consistent results with the maximum possible spread of values on the Izod machine scale.

After investigation of various methods of carrying out the test by both the B.C.I.R.A. and the Technical Advisory Panel, no entirely satisfactory procedure was established which could justify immediate standardisation, but the results have been sufficiently promising to enable a recommended procedure for the test to be published and to be adopted by industry for a trial period, after which possible standardisation will again be reviewed.

The impact test measures a property not determined by any other mechanical test—thus, there is not necessarily any connection between the tensile and transverse strength and the impact resistance of an iron

casting, phosphorus for instance having a greater effect on toughness than on the other mechanical properties.

ACKNOWLEDGMENTS.

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REFERENCES.

- (1) E. M. CURRIE and R. B. TEMPLETON : *Foundry Trade Journal*, 1942, vol. 66, Feb. 26, p. 133.
- (2) Report of Committee A-3 on Cast Iron, *Proceedings of the American Society for Testing Materials*, 1941, vol. 41, p. 86 (see p. 88).
- (3) Report of Sub-Committee XV. on Impact Testing, *Proceedings of the American Society for Testing Materials*, 1933, vol. 33, Part I., p. 87.
- (4) J. G. PEARCE : First Report of the Research Committee on High-Duty Cast Irons for Engineering Purposes, *Proceedings of the Institution of Mechanical Engineers*, 1938, vol. 140, p. 163.
- (5) J. W. DONALDSON : *Foundry Trade Journal*, 1940, vol. 63, Aug. 8, p. 91.
- (6) W. W. BRAIDWOOD : *Foundry Trade Journal*, 1942, vol. 67, May 14, p. 67.
- (7) W. W. BRAIDWOOD : *Foundry Trade Journal*, 1942, vol. 67, June 18, p. 188.
- (8) *Foundry Trade Journal*, 1943, vol. 70, July 22, p. 239.

CORRESPONDENCE.

Mr. A. J. NICOL SMITH (Ministry of Supply, London) wrote : As one who was intimately concerned with the development of the original B.C.I.R.A. test in 1938 and has had the opportunity of following closely the work presented in this paper, I should like to congratulate the authors on bringing us a definite step nearer to a satisfactory shock test for cast irons.

The impact test described in the paper is a shock and not a notch-sensitivity test, as is, for example, the Izod test applied to steel. This is true regardless of the possible notch effect of any graphite flakes present, when the test is regarded as a test of material. This being so, it may be that correlation could be obtained between the impact values and other mechanical properties. Resilience figures have often been used in this connection, and the comparison of these with the impact strengths of different irons would be interesting.

It would be difficult to arrange to carry out by static loading a test similar to the present impact, but such a test might give information on the part played by dynamic loading. Alternatively, it would be useful to know if any experience exists of the effect of variation of blow velocity.

It would be interesting to know if the authors have noted any relationship between the values obtained with the present striking height of 22 mm. and the old test where the value was 1.3 in. Such a relationship could hardly be exact, since, as the striking height is lowered the bend aspect of the test lessens, and the shear properties play a larger part. However, in view of the comparatively large number of published results with the old test a conversion factor would be valuable if it could legitimately be used. From the results in Fig. 20 it would appear that a factor of about 1.25 : 1 would be suitable but not very dependable.

It was found when using the old test that the surface finish of the specimens was not of any great importance, but the results leading to this conclusion were not extensive. Possibly the authors could comment on this aspect.

Mr. M. M. HALLETT (Sheepbridge Stokes Centrifugal Castings Co., Ltd., Chesterfield) wrote: The experiments reported in this paper represent a great deal of work, and the authors are to be commended for the patience shown in their endeavours to establish an entirely satisfactory impact test for grey cast iron, in the face of results which were frequently the reverse of encouraging. In the existing circumstances, the choice of the Izod machine as the instrument for the test was wise, and the evidence clearly points to the modified B.C.I.R.A. procedure as the most satisfactory of those studied, though the results are still not as reproducible as might be desired. It is particularly satisfactory to have the mechanism of the double blow demonstrated so clearly.

Having reached the present stage of the issue of the test as a recommended procedure with the possibility of eventual standardization, it is pertinent to consider the precise purpose for which the test is designed. The authors remark that the impact test measures a property not determined by any other mechanical test. It may be suspected that this claim is unconsciously influenced by the notched-bar impact tests widely used for steel, which certainly do reveal material characteristics not determined by the tensile test, for example. There is, however, a fundamental difference between the Izod impact test used on steel and the test described by the authors for cast iron. The Izod notched-bar impact test is designed to assess the behaviour of steel under concentrated stress conditions which do not permit of ready deformation by shear, in contradistinction to the tensile test which permits shear to occur. In the case of cast iron, the mechanism of failure in the tensile test does not differ markedly from that in the authors' impact test. It is improbable that the difference in speed of testing is a major factor in either case.

In the writer's limited experience of impact testing of cast iron, the conclusion has been reached that there is a definite relation between the impact value and the tensile strength, provided that the basic micro-structure of the irons being studied does not change. As the authors state, if the amount of the phosphide constituent is increased, then the toughness falls in relation to the tensile strength, while if part of the pearlite is substituted by retained austenite (as in the nickel-molybdenum high-strength grey irons of "acicular" structure), the impact value rises in relation to the tensile strength, this probably being even more marked when the irons are fully austenitic. In other words, in unalloyed grey cast iron at any rate, it appears that the impact value can be closely predicted from a knowledge of the tensile strength and the chemical composition. The evidence presented in the paper seems to confirm this suggestion, but it would be of great interest to have the authors' views, in the light of their extensive experience.

If this conclusion is accepted, there would appear to be no point in incorporating the impact test as an additional quality requirement in the existing British Standard Specifications for grey cast iron. In the writer's view, the test will find its most useful application in development work, where it is desired to determine the general toughness of some new cast iron in relation to that of existing types and in assessing the relative shock resistance of fundamentally different types of cast iron.

The question of nomenclature should be settled as soon as possible. The authors have obviously and rightly taken care to avoid the use of terms which might give rise to confusion with the Izod impact test as

applied to steel. It will probably be desirable to avoid altogether the use of the name "Izod" in this connection, but the word "impact" should be retained. It would be a deserved tribute to the efforts of the Technical Advisory Panel, as well as a fair statement of fact, if the proposed test were officially christened the T.A.P. Impact Test for Cast Iron.

Mr. B. E. HOPKINS (The Mond Nickel Co., Ltd., Development and Research Department, Birmingham) wrote: The successful development of a mechanical test is, at the best of times, a painstaking operation, since there are so many variables that have to be separated and examined. In this particular case the burden of those principally concerned with the development of an impact test for cast iron was somewhat lightened by the co-operation and support they enjoyed from a number of industrial concerns. This paper should be welcomed, since it appears at a time when high-duty irons are being developed rapidly and used in fields which were formerly confined to steels, and the need for impact data is apparent.

One of the difficulties attached to evaluating the consistency of results obtained under a given set of testing conditions and the sensitivity of a test to small variations in testing procedure lies in procuring batches of material of sufficient uniformity, this being particularly true of castings. There seems little doubt, therefore, that some of the variation in results obtained by the authors was due to non-uniform material and was not a function of the test or testing procedure at all. The impression I have formed after using for a considerable period the impact test finally recommended in the paper is that it gives reasonably consistent results and is capable of differentiating between various types of cast iron. The variation in results obtained on any one cast iron is naturally somewhat greater than in the standard Izod test on rolled steel (although this is a different test, comparison of scatter of results may be justified), but it is considerably less than is normally obtained when the Izod test is applied to cast steel. A factor of importance is that a substantial spread of results has been obtained at the lower end of the scale, thus showing a marked difference between the more brittle irons and the tougher high-duty irons.

As would be expected from the authors' statement that austenitic irons frequently need more energy to break than the 120 ft.lb. capacity of the machine when using a 0.798-in. dia. test-piece with a 1.3-in. striking height, it has been found that this is true also when the recommended test-piece of 0.798-in. dia. with a striking height of 22 mm. is used. Although this is perhaps unfortunate, it is undoubtedly of greater importance to have the test so adjusted as to obtain the satisfactory spread of results for the more common irons.

Early in the paper it is stated that one of the considerations which guided the Sub-Committee of the Technical Advisory Panel in the choice of test-pieces was that a sharp notch is "undesirable in a material of the nature of cast iron." This view was not adhered to very closely, because test-pieces with notches of various forms were subsequently tried. The reason why a sharply notched test-piece is undesirable does not become apparent until near the end of the paper in Fig. 20, where the results for the test-pieces shown in Fig. 19 are presented. The impact values for the first and last test-pieces, the former being of 0.798-in. dia. at the root of the notch and the latter of the same diameter and unnotched, can be compared, since the area to be fractured is the same in each. The results on the six irons tested range from 4 to 14 ft.lb. for the notched test-piece and from 4 to 29 ft.lb. for the unnotched test-piece. The notch made no difference to the impact value of the most brittle iron, but resulted in values obtained for the other irons being reduced considerably. Thus it appears that a notched test-piece is undesirable, because the range of

values obtained with different irons is so much decreased. If this is the reason the Sub-Committee had in mind when drawing up its original guiding considerations, it is unfortunate that it was not confirmed at an earlier stage in the work.

It is perhaps unfortunate in one respect that a chronological order of reporting has been employed, because the reader is impressed by the "considerable" energy involved in the second blow which the test-piece receives, only to find eventually that the impact value is not affected. Although the explanation for the occurrence of the double blow suggested by the authors is feasible, it is considered that the emphasis placed on and the conclusion drawn from the high-speed photographs are not fully warranted. Unfortunately, the lighting does not appear to have been too well oriented; the knife-edge and the side of the test-piece which receives the blow are in deep shadow, the impression thus obtained being that the fractured portion of the test-piece slides on the knife-edge, and the incidence of the second blow is not at all clear. One would have thought that the evidence obtained by using coloured paints on the knife-edge, the under-surface of the tup, and the anvil would have been given greater weight in arriving at the explanation suggested for the second blow.

A special word of commendation is due to the investigator who experimented with a number of forms of test-piece, examples of which are shown in Fig. 6.

AUTHORS' REPLY.

The AUTHORS wrote in reply : We wish to express our thanks to those who have contributed to the correspondence and for their appreciative remarks concerning the work covered by the paper.

Replying to the specific points raised by Mr. Nicol Smith, we have attempted to correlate a few resilience values determined by the transverse testing of 1.2-in. dia. test bars with corresponding impact results, and it would appear that a relationship might exist, but this requires more detailed investigation. Tests have been carried out using the machine as described in the paper, but with a reduced capacity. This was achieved by reducing the height of fall of the pendulum, which gave, as a result, a lower striking velocity. It was found that when the capacity of the machine was reduced to 60 ft.lb. the impact values obtained were, within experimental limits, the same as those obtained with the full capacity, but the fractures were more irregular and there was a tendency to jamming due to fracture below the grips. It is agreed that, owing to the differing characteristics of the test, no close correlation can be expected between the tests using a 22-mm. striking height on the one hand and a 1.3-in. on the other. It has been found that the increase due to a 22-mm. striking height is approximately 1 ft.lb. for 5-ft.lb. irons, and 8 ft.lb. for 30-ft.lb. irons, with a proportional increase for intermediate impact values.

On the question of surface finish, tests have been carried out using ground and very roughly machined test-pieces, and no differences due to surface finish were discerned within these wide limits. No tests, however, have been carried out on superfinished specimens.

We agree with Mr. Hallett's general observation that there is a relation between impact and tensile strength for irons of the same basic microstructure. However, we cannot agree that impact strength may be predicted from a knowledge of tensile strength and chemical composition alone. Irons of the same tensile strength and analysis and the same section size may show important differences in microstructure, for instance, graphite size and distribution, which will profoundly influence the impact

value. Mr. Hallett raised the question of nomenclature; we are in agreement that this should be settled as quickly as possible, so that, as the test comes more into use, there shall be no confusion with the standard Izod test for steel. Further consideration has been given to this, and it is hoped that it will be satisfactorily covered when the draft British Standard for the test is circulated to the industry.

As pointed out by all the contributors, the impact test for cast iron differs fundamentally from the Izod test for steel in that there is no stress concentration through the use of a notch or groove and the notch effect is thereby eliminated. Experience has shown that a better distribution of results is obtained when using the plain bar.

We agree with Mr. Hopkins that the evidence obtained by using coloured paints on the operative parts of the machine and test-piece are more conclusive than the photographic experiments. These latter are merely regarded as confirming the assumptions made on the basis of the other experiments, and they do, in addition, clearly reveal the path taken by the specimen and its somersaulting movement after fracture.

In the early stages of the work we were concerned about the relatively wide range of results from several tests on the same iron, and it is interesting to note that Mr. Hopkins has obtained even greater scatter in impact tests on cast steels than on cast irons.

THE USE OF A TIN UNDERCOAT TO IMPROVE THE CORROSION RESISTANCE OF PAINTED STEEL.*

By ERNEST S. HEDGES, D.Sc., Ph.D., A.R.I.C., AND THE STAFF OF THE TIN RESEARCH INSTITUTE (GREENFORD), AND L. A. JORDAN, D.Sc., A.R.C.Sc., F.R.I.C., M.I.CHEM.E., AND THE STAFF OF THE PAINT RESEARCH STATION (TEDDINGTON).

(Figs. 1 to 3 = Plates XLII. and XLIII.)

SYNOPSIS.

The effectiveness of tin undercoats on painted steel in retarding corrosion has been examined. The investigations covered electrodeposits of tin from both the alkaline and acid tin baths, using thicknesses of 0.000008 and 0.00003 in., and the effect of flash-melting the tin coatings and of oxidizing the tin surface by chemical treatments; in addition, specimens of plain steel, hot-dipped tinplate and phosphated steel were included in the series. Twelve different paints were applied, including linseed-oil paints, nitrocellulose lacquer, stoving paints, and air-drying japans. Accelerated corrosion tests show that treatment with electrodeposited tin, especially when followed by the application of the T.R.I. (Tin Research Institute) anti-rusting oxide film, adds very greatly to the protection afforded by the paints. The best treatment was 0.00003 in. of tin electrodeposited from the sodium stannate bath and further protected by the T.R.I. film.

In the course of investigations on the electrodeposition of tin on steel undertaken by the Tin Research Institute, it was noticed that tin coatings as thin as 0.000008 in. were remarkably effective in preventing the rusting of steel sheet in the indoor atmosphere and had a considerable retarding influence on rusting out of doors. Such coatings are only one-tenth of the thickness of tin ordinarily applied to tinplate of canning quality and less than one-hundredth of that applied to hot-tinned steel articles such as dairy equipment. It did not seem reasonable, therefore, to expect useful service from such thin tin coatings alone, but it appeared worth while to examine the extent to which they influence the protection afforded by the subsequent application of coatings such as paint.

There were reasons for believing that this influence would be beneficial. For example, owing to the war-time scarcity of tin, it has been necessary in the United States to substitute a lacquered electrolytic tinplate for much of the hot-tinned tinplate formerly used. The new material carries only about one-third of the tin coating applied to the older tinplate and its successful performance under mild conditions depends on the coating of lacquer; but it may also be said that the satisfactory performance of the lacquered sheet depends on the thin tin coating below the lacquer, as it has not been possible to make a directly lacquered steel container which is entirely satisfactory for wet packs.

Lacquered steel products are greatly improved if the surface of the steel is phosphated before lacquering. In this process the surface layer of the steel (about 0.0002 in. deep) is converted into a relatively thick layer (about 0.0003 in.) of phosphates of iron and other metals, and the product has been used during the tin shortage as a substitute for tinplate

* Received March 14, 1945.

in packing non-corrosive substances. It is, however, generally agreed that lacquered phosphated steel is inferior to lacquered thinly electro-tinned steel as a packaging material.

Information on the protective effect of thin tin coatings is given by Kronsbein¹ who has reported the results of corrosion tests on painted steel specimens pickled by the Bullard-Dunn process.² In this process the steel article is treated cathodically in hot sulphuric acid containing stannous sulphate. Hydrogen is liberated in copious amounts and assists in blasting off the scale, while a thin film of tin is simultaneously deposited on the cleaned areas. When pickling is complete, the whole surface of the article is thinly coated with tin; the process is described in detail by Fink and Wilber.³

Kronsbein reports that in accelerated corrosion and ordinary atmospheric-exposure tests of steel specimens coated with a variety of paints after different preliminary treatments, the specimens cleaned by the Bullard-Dunn process with the tin deposit not removed were, on the average, corroded about a quarter as much as the uncleaned specimens and about half as much as the shot-blasted, phosphated specimens.

EXPERIMENTAL METHODS.

The plan of work provided for the corrosion testing of panels of mild-steel sheet coated with tin as described below and subsequently painted with representative paint compositions. For purposes of comparison a number of cleaned steel panels were painted directly, omitting the tin undercoat, and a further series was phosphated before painting. The electro-tinned panels were prepared at the Tin Research Institute and the phosphated panels were prepared by a firm specializing in that treatment. There was as little delay as possible between the phosphating treatment and the painting. All the panels were painted at the Paint Research Station and were subjected to their standardized accelerated weathering test, to their accelerated corrosion test and to outdoor weathering. At suitable intervals the panels were examined jointly by representatives of both research organizations.

The Steel Base.

Two types of mild-steel sheet were used. The first, referred to as "cold-reduced steel," was Ebbw Vale "white-to-edge" plate, 0.011 in. thick; the second, referred to as "pack-rolled steel," was of South Wales origin, 0.011 in. thick. Their analyses were as follows:

					Cold-Reduced Steel.	Pack-Rolled Steel.
Carbon.	%	.	.	.	0.08	0.10
Manganese.	%	.	.	.	0.34	0.40
Silicon.	%	.	.	.	0.001	0.005
Phosphorus.	%	.	.	.	0.019	0.082
Sulphur.	%	.	.	.	0.026	0.075
Copper.	%	.	.	.	0.018	0.110
Nickel.	%	.	.	.	0.046	0.165
Chromium.	%	.	.	.	0.017	0.050

The size of panel was 6 × 3 in. for accelerated weathering and corrosion tests and 8 × 6 in. for outdoor weathering tests.

Tin Coatings.

Two types of electro-tinned coatings were applied: (1) From the acid bath (stannous sulphate plus sulphuric acid), and (2) from the alkaline bath (sodium stannate plus sodium hydroxide). The current densities used

were 10 and 15 amp./sq.ft. for the acid and alkaline bath respectively; the other conditions of electrodeposition are as described by Baier.⁴

Two thicknesses of tin coating were applied, namely 0.000008 and 0.00003 in. (2 and 8 oz. per basis box.) *

In addition to the as-deposited tin surfaces, other surface treatments of tin were included in the tests as follows: (a) In sets of panels coated with 0.00003 in. of tin from both the acid and the alkaline bath, the tin coating was flash-melted by immersing momentarily in palm oil at a temperature slightly above the melting point of tin. (b) Sets of panels carrying 0.000008 and 0.00003 in. of tin from the alkaline bath were treated with the Tin Research Institute anti-rusting oxide film.⁵ (c) One set of panels coated with 0.000008 in. of tin from the alkaline bath was treated with an oxide film by immersing in a phosphoric-acid-chromic-acid mixture.

A set of panels of commercial hot-tinned tinplate was also included. These had a base of pack-rolled steel and a tin coating thickness of 0.000076 in. (20 oz. per basis box).

List of Panels and Coding.

In all 420 panels were included in the tests. All the treatments before painting are listed in Table I., to which is attached a key to the code marks.

TABLE I.—*Treatments of Test Panels before Painting.*

Code Mark.	Steel.	Treatment.	No. of Panels.	
			8 × 6 in.	6 × 3 in.
CS	Cold-reduced	Degreased	7	14
PS	Pack-rolled	"	7	14
CB	Cold-reduced	Phosphated	7	14
PB	Pack-rolled	"	7	14
CA2	Cold-reduced	Acid tin bath, 2 oz. per basis box	7	14
CA8	"	" " 8 " "	7	14
PA2	Pack-rolled	" " 2 " "	7	14
PA8	"	" " 8 " "	7	14
CK2	Cold-reduced	Alkaline tin bath, 2 oz. per basis box	7	14
CK8	"	" " 8 " "	7	14
PK2	Pack-rolled	" " 2 " "	7	14
PK8	"	" " 8 " "	7	14
CF2	Cold-reduced	Alkaline tin bath, 2 oz. per basis box with T.R.I. film	7	14
CF8	"	" " 8 " "	7	14
PF2	Pack-rolled	" " 2 " "	7	14
PF8	"	" " 8 " "	7	14
CFF2	Cold-reduced	Alkaline tin bath, 2 oz. per basis box. Acid film	7	14
CAM8	"	Acid tin bath, 8 oz. per basis box. Flash-melted	7	14
CKM8	"	Alkaline tin bath, 8 oz. per basis box. Flash-melted	7	14
H20	Tinplate	Hot-dipped, 20 oz. per basis box	7	14

C = Cold-reduced steel.

P = Pack-rolled steel.

A = Electrofinned from acid bath.

K = Electrofinned from alkaline bath.

F = Oxide-filmed (T.R.I.).

FF = Oxide-filmed (phosphoric acid).

H = Hot-dipped tinplate.

B = Phosphated.

S = Plain steel.

2 = 2 oz. tin coating per basis box.

8 = 8 oz. tin coating per basis box.

M = Flash-melted.

Types of Paint.

Two-coat paint systems—a priming coat and a finishing coat—were applied throughout. The paints used were chosen as being representative

* The basis box is a unit of area equal to 31,360 sq. in. of sheet (112 sheets, 20 × 14 in.).

of various decorative and industrial types. The formulæ are given in the Appendix. They comprised:

- (a) Linseed-oil-base paints as used in structural painting practice.
- (b) Air-drying japan-type paints as used for industrial finishing of many small metal articles.
- (c) Stoving paints as used for industrial finishing of mass-produced articles.
- (d) Nitrocellulose lacquer, used as an alternative to (b) and (c).

(a) *Linseed-Oil-Base Paints.*

Three types of primers were used, with the same finishing coat. The primers were:

- (i) Paint containing 40% of red lead (calculated on the total pigment).
- (ii) Paint containing 5% of red lead (calculated on the total pigment), corresponding to British Standard Specification No. 1033.
- (iii) Paint similar to (ii), but containing no red lead or other corrosion-inhibitive pigment.

The finishing coat consisted of red iron oxide, ground into linseed stand oil.

(b) *Air-Drying Japan-Type Paints.*

Two types of primers were used:

- (i) Air-drying synthetic-resin-base paint containing 5% of zinc chrome (calculated on the total paint), or 10% calculated on the pigment.
- (ii) Paint similar to (i), but containing no zinc chrome or other corrosion-inhibitive pigment.

The finishing coat consisted of the same medium, pigmented to a glossy finish with carbon black.

(c) *Stoving Paints.*

Only one primer was used, containing no corrosion-inhibitive pigment and consisting of black iron oxide, carbon black and extenders ground into varnish made from linseed-stand-oil/tung-oil/Congo-copal (3 : 1 : 2). The finishing coat consisted of rosin/gilsonite/linseed-stand-oil/tung-oil varnish pigmented to a glossy finish with carbon black.

(d) *Nitrocellulose Lacquer.*

Only one primer was used, containing no corrosion-inhibiting pigment and consisting of black iron oxide and carbon black ground into a clear nitrocellulose medium. The finishing lacquer consisted of a nitrocellulose medium pigmented to a glossy finish with carbon black. This coating system is intentionally below the standard used in industrial practice, where corrosion resistance is required.

Painting Procedure.

The panels were painted in the laboratories of the Paint Research Station and the utmost care was taken to prevent any soiling before painting. The panels were wrapped separately in tissue paper and not touched by hand at any time. Care was also taken to apply a uniform thickness of coating. This was done both with brushed and sprayed

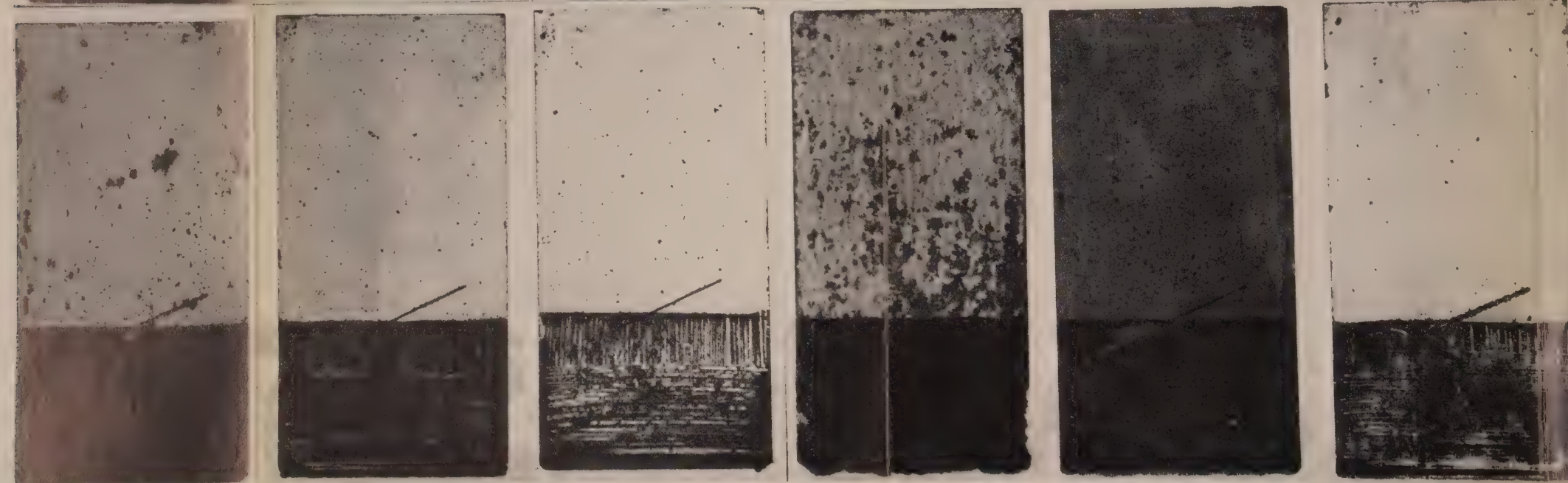
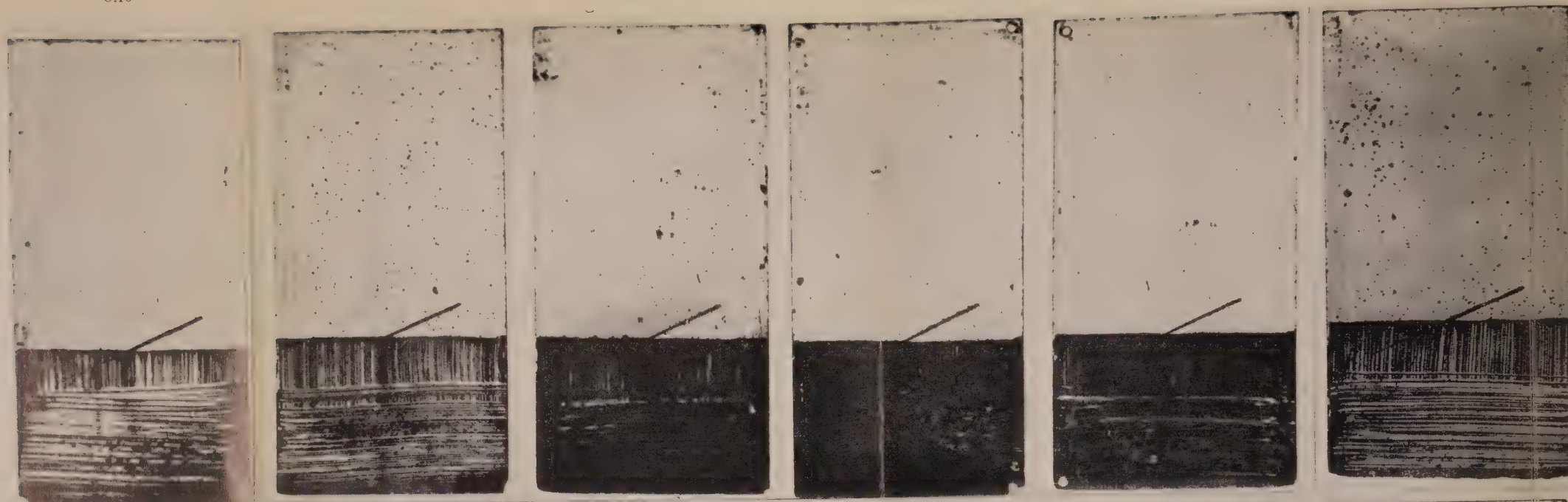
CA8

CK8

CF8

CAM8

CKM8



CK2

CF2

CFF2

CS

CB

H20

MARK.
CA8
CK8
CF8
CAM8

TREATMENT.
Acid tin bath; 0.00003 in.
Alkaline tin bath; 0.00003 in.
Alkaline tin bath; 0.00003 in. with T.R.I. film.
Acid tin bath; 0.00003 in. flash-melted.

MARK.
CKM8
CA2
CK2
CF2

Steels cold reduced; H20 = tinplate.
TREATMENT.
Alkaline tin bath; 0.00003 in. flash-melted.
Acid tin bath; 0.000008 in.
Alkaline tin bath; 0.000008 in.
Alkaline tin bath; 0.000008 in. with T.R.I. film.

MARK.
CFF2
CS
CB
H20

TREATMENT.
Alkaline tin bath; 0.000008 in. with acid film.
Degreased.
Phosphated.
Hot-dipped 0.000076 in.

PAINT: Linseed-oil-base paint containing 40% of red lead.

TEST: 1750-hr. accelerated corrosion test.

FIG. 3.—Rusted Panels after Stripping Paint (Set 4).

coatings by dealing with the panels in sets and not as single items. All the linseed-oil-base paints were applied by brush and the remainder by spray. In each case at least 24 hr. were allowed for the primer to dry before application of the finishing paint. The panels were painted on both sides. In the case of the linseed-oil-base paints only two-thirds of the primer surface was covered with finishing paint, the remaining one-third of the primer at the bottom of the panel being left exposed. A diagonal scratch, 2 in. long and penetrating to the steel, was made on the face of each panel with a sharp-pointed knife. In the case of the linseed-oil-base paints the scratch extended over the boundary between the exposed primer and the finishing paint.

NATURE OF TESTS.

Three tests were employed :

(1) *Outdoor Exposure*.—Panels (8 × 6 in.) were exposed at 45°, facing south, on the laboratory roof at Teddington.

(2) *Accelerated Weathering*.—Panels (6 × 3 in.) were exposed for 1000 hr. in an accelerated weathering apparatus. Details of the test are as follows : An uncured carbon arc, enclosed in resistance glass and consuming across the arc between 800 and 950 W., is suspended eccentrically (approx. 6–10 in. distant from the centre) in a cylindrical container (approx. 4 ft. dia.) with vertical sides to which the panels are attached. The container is revolved slowly (approx. 3 revolutions per hr.), an arrangement which ensures even exposure of the panels to the radiation of the arc and regular wetting by means of a fine spray of rain-water suitably disposed in the container so as to impinge on the panels one-quarter of a revolution before reaching the point nearest to the arc. After the 1000-hr. test individual panels in many of the sets showed little or no change; they were, therefore, subjected to a further accelerated corrosion test, details of which are given under (3).

(3) *Accelerated Corrosion*.—Panels (6 × 3 in.) were exposed to an accelerated corrosion test involving a 24-hr. cycle consisting of (a) a 16-hr. exposure in the accelerated weathering apparatus described above, followed by (b) an 8-hr. exposure in an atomized mist composed of 270 g. of Tidman's sea salt, 37.5 ml. of concentrated sulphuric acid (sp. gr. 1.84), and 10 litres of water. The cycle was repeated until at least some of the panels in each series showed appreciable corrosion.

EVALUATION OF RESULTS.

The exposed panels were examined at intervals during the test for the onset and development of rust, special attention being paid to the behaviour at the scratch mark. On the whole, there was no appreciable breakdown of the paint coatings, but rusting occurred underneath the paint; in some cases patches of paint were blistered. In spite of the long duration of the tests there was (with few exceptions) not much rust to be seen at the painted surface. On some panels there was appreciable spread of rust from the scratch, but on others, where there was an equal spread, it was not noticeable, as the paint coating was not much disturbed thereby. These facts made the fair assessment of the relative degree of corrosion of the painted specimens somewhat difficult. Photographic representation of the results was also marred to some extent by the colour of the paints, which, being either red or black, provided very little photographic contrast with rust. A favourable set of photographs is reproduced in Fig. 1, in which only the blistered paint was removed from the panels.

In view of these difficulties, it was considered desirable, whilst photographing certain suitable sets of painted panels, to remove the paint

from one side of all the panels (by means of a commercial paint remover) and grade the panels by an arbitrary scale according to the degree of rusting of the metal surface. This was done independently by five experienced observers, allocating the value 4 to the most rusted and the value 1 to the least rusted panel in each set. The individual results thus obtained were satisfactorily consistent and from them a mean grading for each panel was calculated (*see* Table II.). The de-painting procedure was also admirably adapted to the photographic representation of the rust on all panels (*see* Fig. 3), but the comparison is unfair to the phosphated panels, owing to the dark colour of the phosphate coating. This difficulty was overcome by afterwards removing the phosphated coating by dipping the panel in cold 5% hydrochloric acid for 30 sec. (a treatment which was too mild appreciably to affect the rust spots), and then comparing the panel with the corresponding panels of de-painted plain steel and of the best tin-treated steel (*see* Fig. 2).

EXPERIMENTAL RESULTS.

Outdoor Exposure Tests.

After exposure to natural weathering for 2 years, the majority of the panels showed little rusting. Detailed presentation of the results will be withheld, therefore, until a later stage.

Accelerated Weathering and Corrosion Tests.

All the experimental evidence has been recorded photographically after removal of the paint film so as to reveal the amount of corrosion that had occurred. As it is not practicable to reproduce all the photographs here, only examples are shown (Figs. 1 to 3), and the experimental evidence is presented by recording the average grading of the panels as described above. These results are shown in Table II.

With every painting system the corrosion of the plain-steel panel was much greater than that of any of the treated panels. It was also noticed that on the whole the results were more favourable to the pack-rolled than to the cold-reduced steel—an unexpected result, which may be due to the somewhat rougher surface of the former. Comparison of the electro-tinned panels reveals no appreciable difference between the coatings from the acid bath and those from the alkaline bath (*cf.* CA8 with CK8, PA8 with PK8, PA2 with PK2, and CA2 with CK2). The 0.00003-in. tin coating is more effective than the 0.000008-in. tin coating (*cf.* the 8 series with the 2 series), but the 0.000008-in. coating is remarkably effective when compared with plain steel. A notable exception is in sets 9 and 10 (stoving paints), where the thinnest tin coating has given little effective protection, possibly owing to diffusion of the tin into the steel during the stoving treatment (at 150° C.), with formation of a surface layer of the compound FeSn_2 . The as-deposited tin coatings are in general better than those that have been melted (*cf.* CA8 and CK8 with CAM8 and CKM8), a fact which may again be connected with the rougher surface. On the whole, the relatively thick (0.000076-in.), commercial hot-tinned coating (H20) is quite effective, but adhesion of the paint does not appear to be so good as with the electrotinned coatings. In many cases, panels of hot-tinned tinplate are remarkably free from isolated rust spots, but rust has spread from the edges and from the scratch mark. Treatment of the tin-plated surface with an oxide film gives an improvement in rust resistance in three cases out of four (*cf.* PF2 with PK2, PF8 with PK8, CF2 with CK2, and CF8 with CK8) and appears to improve the adhesion of the paint. The phosphate treatment occupies an intermediate position among the tin treatments.

TABLE II.—Average Gradings of Panels.

Code Mark.	Sets.													Grand Average.
	1.	2.	3.	4.	5.	6.	7.	9.	10.	11.	13.	14.		
CA8	1.0	1.2	1.0	1.2	1.5	2.2	1.6	2.2	1.9	2.6	2.7	2.8	1.8	
CK8	1.0	1.0	1.0	1.6	1.3	1.9	1.3	1.5	2.5	2.3	2.8	1.9	1.7	
CF8	1.0	1.0	1.0	1.9	2.1	2.4	1.7	1.1	2.7	2.3	2.4	2.2	1.8	
CAM8	1.0	1.6	1.2	1.7	2.1	...	3.6	...	2.8	2.5	2.6	2.4	2.2	
CKM8	1.0	1.0	1.2	1.4	1.6	...	3.3	2.8	2.5	1.7	3.0	2.3	2.0	
CA2	1.2	1.6	1.4	1.8	2.8	2.3	3.0	3.9	3.7	1.8	3.4	2.5	2.5	
CK2	1.0	1.0	1.2	2.9	2.5	2.2	3.0	3.9	3.7	2.7	3.9	2.4	2.5	
CF2	1.8	1.8	1.4	2.1	1.8	1.9	1.2	3.9	3.6	1.8	1.3	1.2	2.0	
CF22	2.0	2.1	1.4	2.1	2.0	2.2	2.2	1.2	3.6	2.6	2.1	3.9	2.3	
CB	1.8	1.9	2.2	2.0	1.7	1.9	2.5	1.8	3.3	2.3	2.2	1.3	2.1	
CS	4.0	4.0	4.0	4.0	4.0	4.0	3.2	4.0	4.0	4.0	3.7	4.0	3.9	
PA8	1.2	1.0	1.0	1.2	1.4	1.0	1.1	2.1	2.5	1.8	2.7	1.9	1.6	
PK8	1.8	1.0	1.0	1.3	1.3	1.6	2.1	1.6	1.9	1.9	2.1	2.3	1.7	
PF8	1.0	1.0	1.2	1.6	1.0	1.3	1.7	1.3	1.3	1.1	1.0	2.5	1.3	
PA2	1.6	1.9	1.0	2.0	2.2	1.7	2.7	3.2	3.6	2.1	2.8	3.3	2.2	
PK2	1.6	1.2	1.5	2.1	2.2	2.6	3.0	3.9	3.6	1.8	2.6	2.7	2.5	
PF2	1.4	1.2	1.0	1.4	1.2	1.9	1.7	1.3	3.6	1.4	1.1	2.1	1.6	
PB	1.6	1.8	2.0	2.5	2.4	2.1	2.5	1.6	2.4	1.7	2.0	1.8	2.0	
PS	1.4	2.4	2.0	2.8	3.6	4.0	3.4	3.0	4.0	3.8	3.4	3.2	3.1	
H20	1.0	1.0	1.0	1.6	1.9	1.6	2.3	1.9	1.5	2.0	2.3	1.4	1.6	

KEY TO CODES.

Code Mark.	Steel.	Treatment.
CA8	Cold-reduced	Acid tin bath . 0-00003 in.
CK8	"	Alkaline tin bath " "
CF8	"	" " with T.R.I. film.
CAM8	"	Acid tin bath . Flash-melted.
CKM8	"	Alkaline tin bath " "
CA2	"	Acid tin bath . 0-000008 in.
CK2	"	Alkaline tin bath " "
CF2	"	" " with T.R.I. film.
CF22	"	" " with acid film.
CB	"	Phosphated.
CS	"	Degreased.
PA8	Pack-rolled	Acid tin bath . 0-00003 in.
PK8	"	Alkaline tin bath " "
PF8	"	" " with T.R.I. film.
PA2	"	Acid tin bath . 0-000008 in.
PK2	"	Alkaline tin bath " "
PF2	"	" " with T.R.I. film.
PB	"	Phosphated.
PS	"	Degreased.
H20	Tinplate	Hot-dipped . 0-000076 in.

KEY TO SETS.

Set No.	Paint.	Treatment.
1	Linseed-oil-base paint containing 40% of red lead.	1000-hr. accelerated weathering followed by 750-hr. accelerated corrosion test.
2	Linseed-oil-base paint containing 5% of red lead.	" " " " "
3	Linseed-oil-base paint containing no red lead.	" " " " "
4	Linseed-oil-base paint containing 40% of red lead.	1750-hr. accelerated corrosion test.
5	Linseed-oil-base paint containing 5% of red lead.	1000-hr. " " "
6	Linseed-oil-base paint containing no red lead.	" " " "
7	Nitrocellulose lacquer.	1000-hr. accelerated weathering followed by 500-hr. accelerated corrosion test.
9	Stoving paint.	1000-hr. accelerated weathering followed by 750-hr. accelerated corrosion test.
10	"	1500-hr. accelerated corrosion test.
11	Air-drying "japan" containing 5% of zinc chrome.	1000-hr. accelerated weathering followed by 500-hr. accelerated corrosion test.
13	"	1500-hr. accelerated corrosion test.
14	Air-drying "japan" containing no " zinc chrome.	" " " "

The treatments can be arranged in order of merit by taking the average gradings for both steel bases and all the paints. The order is given in Table III., from which it will be seen that the treatments can be classified roughly into three groups: (a) Treatment with 8 oz. per basis box or more of tin, or with 2 oz. of tin followed by the anti-rust oxide film; (b) 8 oz. melted tin coatings, phosphate coating, 2 oz. electroplated coatings; (c) plain steel.

TABLE III.—Order of Merit.

Code Mark.	Treatment.	Average Grading.
F8	Alkaline tin bath 0.00003 in. with T.R.I. film	1.6
H20	Hot-dipped tinplate 0.000076 in.	1.6
A8	Acid tin bath 0.00003 in.	1.7
K8	Alkaline tin bath 0.00003 in.	1.7
F2	Alkaline tin bath 0.000008 in. with T.R.I. film	1.8
KM8	Alkaline tin bath 0.00003 in. Flash-melted	2.0
B	Phosphated	2.1
AM8	Acid tin bath 0.00003 in. Flash-melted	2.2
A2	Acid tin bath 0.000008 in.	2.4
K2	Alkaline tin bath 0.000008 in.	2.5
S	Degreased	3.5 (c)

APPENDIX.—Compositions of Paints Used.

Linseed-Oil Paints for Structural Work.

	Primer I.	Primer II. (B.S. 1033).	Primer III.	Finishing Paint.
Red lead. %	34.75	4.0	...	...
Red iron oxide. %	...	44.0	48.0	60.0
Barytes. %	48.0	28.0	28.0	...
Asbestine. %	4.25	4.0	4.0	...
Pale boiled linseed oil. %	13.0	20.0	20.0	...
Linseed stand oil. %	...	...	...	40.0

In each case, drier (0.05% cobalt) was added to the oil and the paints were thinned to a suitable consistency with white spirit.

Air-Drying Synthetic-Resin-Base Paints (Japan Type).

	Primer I.	Primer II.	Finishing Paint.
Medium A. %	33.3	33.3	48.3
Medium B. %	16.7	16.7	48.3
Titanium white (25% TiO ₂). %	16.3	16.3	...
Zinc chrome (high sol.). %	5.0	...	...
Red iron oxide. %	16.3	21.3	...
Barytes. %	9.8	9.8	...
Asbestine. %	2.6	2.6	...
Carbon black. %	...	...	3.4

Medium A: 1:1 tung-oil/pure-phenolic-resin varnish, 50% non-volatile content.

Medium B: Linseed-oil/modified-alkyd-resin varnish, 50% non-volatile content.

Stoving Paints.

	Primer.
Medium	40.0%
Black iron oxide	32.0%
Carbon black	2.4%
Blanc fixe	24.0%
Asbestine	1.6%

Medium : Linseed stand oil (15 poise) 30.0, tung oil 10.0, fused Congo copal 20.0, white spirit 40.0%.

0.01 cobalt and 0.1% lead on oil as driers.

Finishing Paint.

Medium	.	.	.	.	.	95.25%
Carbon black	.	.	.	.	.	4.75%

Medium : Gilsonite (run) 20.0, rosin 10.0, tung oil 12.0, leaded linseed oil (3.7% lead) 4.0, flake litharge 0.6, turps 26.7, white spirit 26.7%.

0.1 manganese and 0.05% cobalt on oil and gilsonite.

Nitrocellulose Lacquers.

				Primer.	Finishing Lacquer.
Clear lacquer.	%	.	.	77.0	97.25
Black iron oxide.	%	.	.	15.4	...
Carbon black.	%	.	.	3.8	2.75
Asbestine.	%	.	.	3.8	...

Clear lacquer : $\frac{1}{2}$ -sec. nitrocotton 19.3, ester gum 15.5, dibutyl phthalate 3.4, solvent mixture 61.8%.

REFERENCES.

- (1) J. KRONSBORN : *Journal of the Electrodepositors' Technical Society*, 1940, vol. 16, pp. 55-60.
- (2) U.S. Patent No. 1,775,671 (1930).
- (3) C. G. FINK and T. H. WILBER : *Transactions of the Electrochemical Society*, 1934, vol. 66, p. 381.
- (4) S. BAUER : *Publication of the International Tin Research and Development Council* No. 92 (1939).
- (5) R. KERR : *Journal of the Society of Chemical Industry*, 1940, vol. 59, Dec., p. 259.

CORRESPONDENCE.

Dr. A. L. WILLIAMS (Westinghouse Brake and Signal Co., Ltd., Chippenham, Wilts) wrote : A few months ago we carried out experiments, the results of which in general support those reported in the paper.

In a certain application, we were using a stoving enamel (glyptal/red-iron-oxide) on articles made up partly of cadmium-plated steel nuts, screws, washers, &c. On subjecting the articles to the usual "tropical" tests, it was soon found that the paint adhesion was very bad and that blistering and stripping took place rapidly. As the type of enamel could not be changed at that time, an alternative metal coating had to be sought.

Specimens were prepared on steel bases, using all the metals commonly electrodeposited, and also, in the case of zinc and cadmium, applying the phosphate and chromate surfacing treatments.

The metals were deposited in normal commercial thicknesses and phosphated unplated steel specimens were included for comparison purposes.

The specimens were painted and tested under K110* and salt-spray conditions. At regular intervals, one example of each type of surface was removed and the paint adhesion checked by visual observation and by stripping.

As the results of the two methods of test were in good agreement,

* A cyclic humidity test covered by Wireless Telegraphy Board Specification K110 (Electrical Telecommunication Apparatus for Use in Damp Tropical Climates).

the salt-spray test was discontinued after 1000 hr., but the *K110* test was carried to 21 wet cycles. The main conclusions were as follows :

(1) The initial paint adhesion to the different surfaces varied considerably and electrodeposited tin was inferior to several others.

(2) Only phosphated steel maintained its adhesion throughout the test, but electrodeposited tin deteriorated only a little, and after a few *K110* cycles or a few hundred hours' salt-spray was far superior to the remainder, which aged at varied but rapid rates.

(3) Judging the specimens from all aspects, electrodeposited tin was slightly superior to phosphated steel, as the latter showed a few small rust spots at the end of the test.

Dr. J. C. HUDSON (Birmingham) wrote : The authors' results bring out clearly the value of protective schemes for iron or steel comprising a thin metallic undercoat followed, after appropriate chemical surface treatment, by paint, and thus lend support to one of the views recently expressed by a Committee of the British Standards Institution regarding the protection of light-gauge steel or wrought-iron parts used in permanent building construction, namely, that when used inside buildings in positions where heavy corrosion is probable such parts should be given a metallic coating followed by two coats of paint; the metallic coating might suitably consist of zinc, aluminium, cadmium, lead, *terne* (lead-tin alloy) or tin, and, where appropriate, should receive a chemical surface treatment before painting.* In the course of collaborative experimental work by members of this B.S.I. Committee, similar evidence has been revealed of the marked benefits to be obtained by the use of thin zinc coatings, some 0.00005 in. thick, if these are phosphated before the application of the paint.

It is possible that the superiority under test of the pack-rolled steel as compared with the cold-reduced steel is due rather to the fact that it contains 0.11% of copper, 0.17% of nickel and 0.05% of chromium, than to any difference in surface roughness. The artificial sea-water spray used was strongly acid (approximately 0.14*N* with regard to H_2SO_4) and under such conditions the presence of these elements would reduce rusting appreciably.

It would add materially to the value of the data, more particularly when the authors proceed to publish the results of the outdoor exposure tests, if they would add figures for the thicknesses of the respective paint films to the data concerning the formulation of the paints which they give in the Appendix. Film thickness has an important bearing on the behaviour of a protective painting scheme and it is desirable that it should be stated in work of this kind. As an alternative to direct measurement, it would suffice to state the coating weight together with the specific gravity of the mixed paint, its volatile content and the specific gravity of the volatile matter, from which a reasonably accurate value for the film thickness could be calculated.

Mr. C. P. LARABEE (Vandergrift, Pa., U.S.A.) wrote : This paper has been read with interest. I presume that the authors have ascertained by previous tests that a satisfactory relationship exists between the accelerated test and outdoor weathering. The lack of adherence of the paint adjacent to the scratch on panels *PB* and *CB* in Fig. 1 shows that the authors' accelerated test is indeed severe.

* "Recommendations on Methods of Protection against Corrosion for Light Gauge Steel and Wrought Iron Used in Permanent Building Construction." The British Standards Institution, P.D. 420, Nov., 1945.

The only statement in the text to which exception is taken is on p. 434 P, where the better performance of the pack-rolled over that of the cold-reduced steel is ascribed to the "somewhat rougher surface of the former." In our opinion a more likely explanation of this difference is the high percentage of copper and nickel in the pack-rolled steel. The pack-rolled steel with 0.11% of copper and 0.17% of nickel would be much more resistant to atmospheric corrosion than the cold-reduced steel with its 0.018% of copper and 0.05% of nickel. We have found that the comparatively voluminous rust on steel with low copper spreads under paint faster than the more protective rust that forms on copper steel.

The superiority of copper steels over plain steels as a base for paints has been shown by many other investigators, among whom are K. G. Lewis and U. R. Evans,* and S. C. Britton and U. R. Evans.†

Dr. T. P. HOAR (University Chemical Laboratory, Cambridge) wrote: These results, which show beyond doubt the improvement to be had by the use of thin electrodeposited tin undercoats in conjunction with several usual two-coat painting systems in the protection of steel, make one ask for more. There are, without doubt, numerous small steel structural members that could be electrotinned before erection or fabrication and then receive a two-coat painting system; but there must be many more such components for which, on account of size and/or cost limitations, such an electrotinned coating would be impracticable. It would therefore be of the greatest interest to have results, comparable with those given in the paper, for thin tin undercoats applied by the wire- and powder-spraying processes and by the Bullard-Dunn pickling process, which methods might well be practicable in many cases where electrotinning was not. Furthermore, there may be practical cases where it would be economic to use a tin undercoat of some kind *in place of*, but not in addition to, a usual paint primer of the red-lead or zinc-chromate type, and yet other cases where the substitution of a tin undercoat for such primers might be technically attractive, as in acid industrial atmospheres; here again, comparative experimental results would be very welcome, and we may hope that more collaborative work such as that now reported may provide them. Finally—though perhaps it is a little unkind to address the suggestion to at any rate one of the collaborating parties—I believe that a comparison of tin with cadmium undercoats might be interesting, at least for acid atmospheres, for the inhibition of steel corrosion given by dissolved tin ions is also given by cadmium ions, under mildly acid conditions.‡

The authors deserve our thanks for their precise descriptions of, or references to, the types of paints and tinning methods used. If they themselves are not able to continue the work and provide *inter alia* the information that I have suggested above would be useful, it will be easy for others to do so.

AUTHORS' REPLY.

The AUTHORS wrote in reply: We are glad to receive general confirmation of our results from Dr. Williams and to know that in his tests on painted specimens he had observed the beneficial effect of tin as an under-

* Third Report of the Corrosion Committee, Section D, Part 5, *The Iron and Steel Institute*, 1935, *Special Report* No. 8.

† *Journal of the Society of Chemical Industry*, 1936, vol. 55, Dec. 4, pp. 337 T-344 T.

‡ T. P. Hoar and D. Havenhand, *Journal of The Iron and Steel Institute*, 1936, No. I., p. 239 P.

coat. The suggestion put forward by Dr. Hudson and by Mr. Larrabee concerning the influence of the copper and nickel content on the rusting of steel is probably the correct explanation of the better performance of the pack-rolled steel over that of the cold-reduced and we are grateful to be reminded of this factor.

The thicknesses of the respective paint films, requested by Dr. Hudson, are given below :

Set No.	1 and 4.	2 and 5.	3 and 6.	7.	9 and 10.	11 and 13.	14.
Thickness, in.	0.0026	0.0026	0.0028	0.0014	0.0021	0.0025	0.0031

In reply to Mr. Larrabee, it is not possible, of course, to get a general relation between an accelerated corrosion test and outdoor weathering of all kinds, for there is considerable divergence in the effects of different atmospheres; but experience at the Paint Research Station has shown that the accelerated corrosion test used does give results which are reasonably parallel with those obtained on exposure to similar activating agencies (salt and acidity) such as are found in an industrial-marine atmosphere. The test was intended to be severe.

Dr. Hoar refers to the possibility of using a tin undercoat in place of a paint primer of the red-lead or zinc-chromate type. Actually, the results given in Table II. show that the tin undercoat is more effective than red lead or zinc chromate. This can be seen by comparing the average gradings for steel (*CS* and *PS*) coated with paints containing the oxidising pigment with those for tin-coated steel (*CF8* and *PF8*) having the same paint system but without the oxidising pigment. Thus in set 1 (40% red lead) the gradings for *CS* and *PS* are 4.0 and 1.4, and in set 2 (5% red lead) they are 4.0 and 2.4, whilst in set 3 (no red lead) the gradings for *CF8* and *PF8* are 1.0 and 1.2, respectively. Again, in set 5 (5% red lead) the gradings for *CS* and *PS* are 4.0 and 3.6, respectively, whilst in set 6 (no red lead) the gradings for *CF8* and *PF8* are 2.4 and 1.3. A further comparison is afforded by sets 13 and 14 (5% zinc chromate and no zinc chromate, respectively); here the gradings for *CS* and *PS* are 3.7 and 3.4, and those for *CF8* and *PF8* are 2.2 and 2.5.

Dr. Hoar's remark on cadmium as an undercoat for paint seems to have been opportunely answered by Dr. Williams.

THE IMPROVEMENT OF THE CITRIC-ACID SOLUBILITY OF BASIC OPEN-HEARTH SLAGS CONTAINING FLUORSPAR.*

By T. F. PEARSON, M.Sc. (MESSRS. COLVILLES, LTD., CLYDEBRIDGE).

SYNOPSIS.

Brief mention is made of the citric-acid solubility test for basic slags. A survey of the order of solubility for slags from both fixed and tilting furnaces when fluorspar is used follows. Tapping-slugs were found to be 10–20% soluble for fixed furnaces and 20–30% soluble for a tilting furnace with current practice.

Preliminary experimental work was conducted to discover the effect of quenching, and it was found by this means that the solubility could be increased considerably. The severity of the quench appeared to influence the results. Further work in the laboratory involved the sintering of powdered low-solubility slags with sodium carbonate and other sodium compounds. The former proved to be the most effective, and, by the use of a sufficient quantity, any slag could be rendered completely soluble. The efficiency of the sodium carbonate became less as the initial solubility of the slag with which it was sintered increased.

Laboratory experiments involving the treatment of slags at high temperatures with steam proved unfruitful.

Results obtained from the sintering experiments prompted full-scale trials in the pitside, and numerous treatments were carried out by feeding sodium carbonate and mixtures of sodium carbonate with sand into slag ladles at tapping. A satisfactory method of sampling these ladles while the slag was liquid was evolved, and it was found that, in spite of the difficulties resulting from a lack of precise knowledge of the actual slag weights, considerable increases in solubility values were obtained.

In the discussion of the results it is suggested that the efficacy of the sodium carbonate depends on its more complete dissociation at high temperatures than the other sodium compounds used. The interpretation of the mechanism of increased solubility is based on the acceptance of the "insoluble" phosphorus existing as $3(\text{3CaO.P}_2\text{O}_5).\text{CaF}_2$ (slightly soluble only). The addition of sodium carbonate results in a substitution of some, or all, of the bonded CaF_2 , with the probable formation of $3(\text{CaO.P}_2\text{O}_5).2\text{NaF}$, or possibly the loosening of the fluoride molecule. Later laboratory experiments disprove the possibility of the formation of sodium phosphate up to the limit of sodium carbonate used, since no "water solubility" resulted from any treatment.

Additions of sand made in the full-scale trials appeared to have some slight effect in increasing the solubility, probably by increasing the tendency towards the formation of some soluble silico-phosphate.

Full-scale trials indicated that, in order to keep down the proportion of sodium carbonate to reasonable amounts, the addition of fluorspar to the furnace would have to be limited to some 4 cwt., approximately, for an 85-ton charge.

Introduction.

It is well known that the addition of fluorspar to a basic open-hearth slag drastically reduces the amount of phosphorus extractable by treatment of the slag with a 2% solution of citric acid under standard conditions. The test evolved by Wagner has been subjected to much criticism from time to time, as to its suitability for determining the immediate value of a slag as a fertiliser. Wagner originally postulated that a 2% aqueous citric-acid solution corresponded reasonably well to the degree of acidity

* Received August 2, 1944.

commonly encountered in soils, and his test, involving 30 min. agitation, was supposed to represent the solvent action exercised by the humus acids present in soil over a period of two years. The absolute validity of such an assumption is open to doubt, since it is shown subsequently that the application of fresh citric acid to the slag, repeatedly, even in the case of a low-solubility slag, is capable of extracting all the phosphorus. Strictly speaking, therefore, there is no insoluble slag. The important point, however, is that various slags do behave differently towards the initial solvent action of a weak organic acid such as citric, and consequently it may be considered that such a test has at least some comparative value. The adoption of citric acid seems one of convenience, since other organic acids, *e.g.*, acetic acid, exercise a similar solvent action, although not to the same degree for equivalent strengths.

In view of the work to be described a brief summary of the test is given. Reference may be made to H.M. Stationery Office Statutory Rules and Orders⁽¹⁾ for further details. A 5-g. sample, of which 80% (min.) is required to pass a 100-mesh British Standard Specification sieve, is shaken for 30 min. in 500 c.c. of 2% citric acid. The shaking is best done by machine, in a standard bottle, at some 30–40 r.p.m., thus ensuring that the mixture “tumbles” well at each revolution. The whole is then rapidly filtered and an aliquot portion of the filtrate taken in which the phosphorus is determined by any suitable method.

While some slags, by virtue of their high total-phosphorus content, might be considered equal in value as plant food, in spite of a lower “solubility,” to equivalent weights of those of a lower total-phosphorus content but higher “solubility,” the present method of valuating is based upon both the total-phosphorus content, and the amount of phosphorus dissolved by citric acid under the stated standard conditions. Hence, a compromise is effected between two possible points of view. The high-solubility slag is still favoured, however, since an increase of 1 soluble unit of phosphorus, *i.e.*, an increase of, say, from 4 to 5% of the phosphorus which can be dissolved by the citric acid, is worth an increase of 2% in the total phosphorus contained in the slag. At the present time, for obvious reasons, slags containing as little as 4–5% of soluble phosphorus are acceptable.

The action of fluorspar in cleaning up a slag and facilitating the furnace coming to boil is well known. Among the minerals available it is quite unique in this respect and no adequate substitute has been found. Bauxite has been used, but this is not available to-day, and the well developed technique involving the use of spar in any melting shop is not easily eliminated without considerable difficulty. A number of theories have been advanced to explain the action of fluorspar, *e.g.*, the lowering of the melting point of the slag and reduction of viscosity, but these explanations are by no means complete.

Present Work.

The provision of phosphates for fertilising purposes is of considerable importance at the moment, owing to the obvious limitations on imports of phosphate rock. Particularly does this apply to Scotland, and the author's Company therefore initiated experiments, the object of which was to discover if some reasonable method of treating low-solubility slags could be evolved which would give improved value and render them marketable. These experiments were undertaken at Clydebridge Steel Works, since here is the only melting shop in the district using the hot-metal process. A measure of success was achieved. Work was conducted in the laboratory and full-scale experiments made in the pitside.

Preliminary Survey of "Solubilities."

Since the fairly generous use of fluorspar in both fixed- and tilting-furnace practice was customary, a survey of the general level of solubility values was first made for both primary (in the case of the tilting furnace) and tapping slags. Numerous analyses showed that, for the tilting furnace, solubilities of the order of 95%, with total P_2O_5 contents of 16–18%, were produced before the addition of spar, while subsequent tapping slags came down to 20–30% solubility, with 12–14% P_2O_5 . Fixed-furnace slag solubilities ranged from 10–20% with total P_2O_5 contents of 8–12%. Slags from the tilting furnace sampled at intervals after the addition of hot metal indicated, as was expected, that the total P_2O_5 content of the slag bore a rough relationship to the length of time elapsing between "furnace full" and the withdrawal of the slag (see Table I.).

TABLE I.—*Influence of Time of Withdrawal on P_2O_5 Content of Slags.*

Time Interval. Hr.	P_2O_5 (approx.). %.
7–8	20.0
8–9½	16–18.0
10–12 (tapping)	12–14.0

These results are in keeping with the mechanism of slag formation, the relative quantities of scrap and hot metal used, and its phosphorus content. Standard methods of working are necessary to secure consistent slag values.

TABLE II.—*Influence of Fluorspar on Solubility of Slag.*

Charge No.	Weight of Spar. Cwt.	Primary P_2O_5 . %.	Primary Solubility. %.	Tapping Solubility. %.
R325. . . .	1	16.55	100	90.5
R351	3	N.d.	N.d.	66.5
R324	4	17.62	100	56.2
Numerous	10–12	N.d.	N.d.	25.0 (aver.)

Table II. shows, quantitatively, the drastic effect of spar additions in reducing the solubility of tilting-furnace slags. It is assumed that the total weight of slag is approximately the same for each charge.

Experiments on the Effect of Quenching.

Lathe⁽²⁾ mentions the increased solubility resulting from the quenching of molten slags, and the process has apparently been carried out on a commercial scale. To confirm this, slag samples were drawn from furnaces approximately 30 min. before tapping. One sample from each was poured in a thin stream from a height of 3 ft. into cold water, and another, drawn at the same time, was allowed to cool normally in the spoon. Typical results are given in Table III.

While the quench was not equally effective in all cases, it appears that the increase in solubility possible by this method is limited.

In view of the results obtainable by quenching from the liquid it was thought of interest to reheat solidified slags to various temperatures and then quench. For this purpose a series of slags was taken from the tilting furnace 1½ hr. after the addition of 8 cwt. of spar. In all, five samples were rapidly withdrawn from the middle door—the first being quenched and the

TABLE III.—*Effect of Quenching on Solubility.*

Charge.	Total P_2O_5 . %.	Soluble P_2O_5 . %.	Solubility. %.
N9605 :			
Slow cool . . .	10.85	1.38	12.7
Quench . . .	10.79	3.23	29.9
P9856 :			
Slow cool . . .	11.31	1.64	14.5
Quench . . .	11.25	4.10	36.4
P9607 :			
Slow cool . . .	12.96	1.62	12.5
Quench . . .	12.70	3.16	24.9

remainder slow-cooled in separate spoons. The last three were crushed, thoroughly mixed and then sieved between 10- and 25-mesh screens. Samples of material of this size were maintained at different temperatures for 1 hr. in nickel crucibles, so arranged as to permit rapid immersion in cold water. These quenched samples were then dried and crushed to pass a 100-mesh British Standard Specification sieve. Results are given in Table IV.

TABLE IV.—*Effect of Heat Treatment and Quenching on Solubility.*

Charge and Treatment.	Total P_2O_5 . %.	Soluble P_2O_5 . %.	Solubility. %.
R218 :			
Slow-cooled in spoon .	13.49	3.01	22.6
Quenched from :			
Liquid . . .	13.59	8.25	60.8
1020° C. . .	13.32	2.87	21.5
930° C. . .	13.40	2.92	21.7
840° C. . .	13.47	2.86	21.2

The effect of quenching from intermediate temperatures below the liquidus is negligible. The 60% solubility achieved by quenching from the liquid, when compared with the results in Table III., confirms that the speed and severity of the quench determines the degree of improvement possible. It is evident that the effect of quenching is partially to prevent the separation of phosphorus in some "insoluble" form. When the slag is reheated to the temperatures stated in Table IV. the insoluble form is not decomposed or redissolved.

All the results, however, indicated that there was no absolute possibility of securing a minimum of 4.5 soluble units in the fixed-furnace slags, since, owing to the relative proportions of scrap and hot metal used, total P_2O_5 contents were more frequently below 10%. Moreover, the difficulties attendant on the effective quenching of full ladles of slag are very considerable and would involve specially constructed ponds.

Laboratory Experiments on Sintering.

The addition of sodium carbonate to the slag, since it is a readily available material, appeared to offer possibilities. It was thought at first that a water-soluble phosphate might be formed, but this was subsequently disproved. Before commencing full-scale experiments in the pitside, laboratory work was first undertaken. Since no facilities were available for conveniently melting slags to which additions might be made, it was decided that sintering might achieve the same ends, since, by treat-

ment at, say, 1000°C ., *i.e.*, above the melting point of sodium carbonate, diffusion into the slag would take place and some measure of its effect would therefore be attainable. Accordingly, samples of the same low-solubility slag (R218, 21.7% solubility, previously ground to pass a 100-mesh B.S.S. sieve) were intimately mixed by further light grinding with anhydrous sodium carbonate covering a range of 1 to 15% of the weight of the slag taken. The mixtures were packed into nickel crucibles, consolidated by tapping, and sintered for 1 hr. at 1050°C . Samples were subsequently cooled in air, crushed, and re-sieved to provide samples for analysis.

The first series was later supplemented by a further series using a different slag, the sintering being carried out at 1000°C for 6 hr. The time of treatment was here extended to compensate for the considerably larger bulks made up.

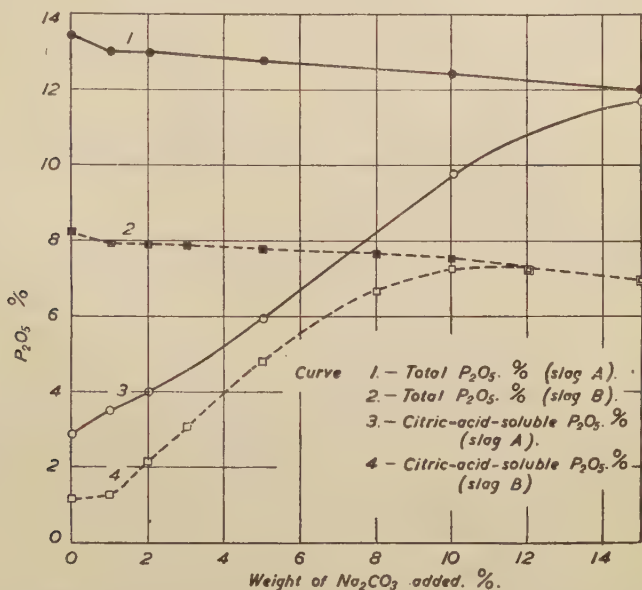


FIG. 1.—Effect of Sintering "Insoluble" Slags with Na_2CO_3 . Slag A, 1 hr. at 1050°C ., slag B, 6 hr. at 1000°C .

Fig. 1 shows the results obtained. If the proportion of sodium carbonate is sufficiently high complete citric-acid solubility is achieved. Also, at the first achievement of 100% solubility, in each case the weight of sodium carbonate necessary for slags A and B is in the same proportion as their total P_2O_5 contents. The curves show that, to effect appreciable necessary increases in the solubility values by this method, comparatively large additions are necessary which would be prohibitive in practice, owing to cost. Also, two opposing possibilities arise: (1) A reasonable conclusion from the foregoing experiments is that the effectiveness of the addition should increase considerably if made to a liquid slag. One might expect the sodium ion to be more active the higher the temperature, possibly necessitating a lesser addition to achieve increased solubility. (2) Additions of sodium carbonate might become less effective the higher the initial solubility of the slag.

The latter point was more easily investigated first, and was carried out

by selecting tapping slags of varying solubility, and treating by sintering exactly as described. The results, together with those shown in Fig. 1, have been incorporated in Fig. 2. For clarity, the total P_2O_5 contents

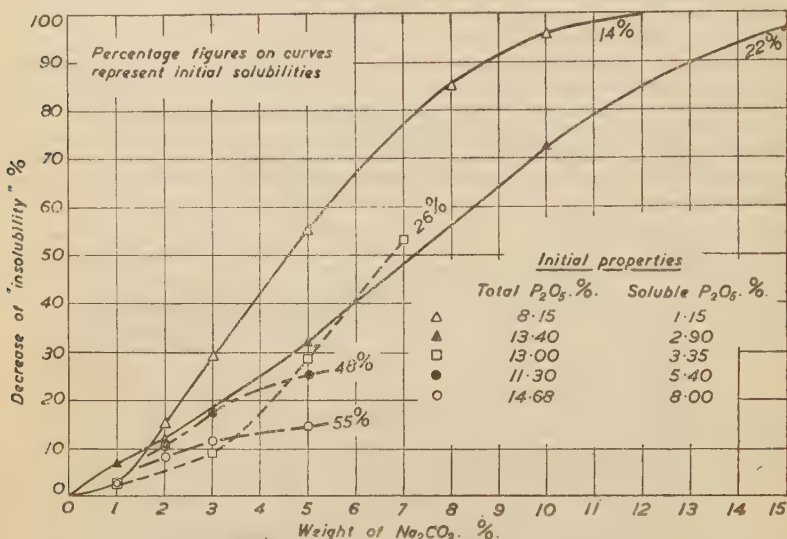


FIG. 2.—Loss of Efficiency of Na_2CO_3 as Initial Solubility Increases.

have been omitted, and to facilitate comparison of the relative slopes the percentage-decrease-in-insolubility values have been plotted against the additions made. The evidence shows that, independent of the total P_2O_5 values for the various slags, the quantitative effect of the sodium carbonate does depend on the initial solubility. As the initial solubility increases, the slopes showing the gain in solubility due to fixed additions, with one exception, become less steep, thus confirming the second of the possibilities referred to above.

The Effect of Other Sodium Compounds.

During the progress of the foregoing experiments the effect of other sodium compounds was tried—chiefly because of their abundance and availability. The same technique was employed and the temperature ($1050^\circ C.$) adequately exceeded the melting points. Of the compounds used, sodium sulphate is actually cheaper than sodium carbonate. The same slag (low initial solubility) was used in all cases, and to simplify comparison the results have been tabulated (Table V.).

The effect of sodium chloride is negligible. This is not thought to be due necessarily to the presence of the chloride, although White⁽³⁾ states that if calcium chloride is used as a flux instead of fluorspar a low-solubility slag results. The effectiveness of both sodium sulphate and the hydroxide is inferior to that of the carbonate, and, beyond being of interest, was not considered worth pursuing further.

One mixture, consisting of 50% by weight of the carbonate was tried, and, after treatment, two separate layers existed, the top consisting of the excess sodium carbonate (white) and the bottom of an intensely hard black glazed block. The system has limits of miscibility and may be of interest for future investigation.

TABLE V.—*The Effect of Various Sodium Compounds on Citric-Acid Solubility by Sintering at 1050° C.*

Weight of Sodium Compound Added. %.	Sodium Chloride.			Sodium Sulphate.			Sodium Hydroxide.		
	Total P ₂ O ₅ . %.	Soluble P ₂ O ₅ . %.	Solubility. %.	Total P ₂ O ₅ . %.	Soluble P ₂ O ₅ . %.	Solubility. %.	Total P ₂ O ₅ . %.	Soluble P ₂ O ₅ . %.	Solubility. %.
0	8.54	1.06	12.4	...	...	...	...	...	...
1	8.35	1.38	16.5	8.35	1.57	18.8	...	...	...
2	8.28	1.31	15.8	8.22	2.22	27.0	...	...	...
3	8.16	1.31	15.9	8.16	2.32	28.4	...	...	...
5	7.91	1.13	14.2	7.97	3.45	43.2	8.01	3.26	40.6
8	7.78	1.31	16.7	7.91	3.51	44.3	...	...	...
10	7.72	1.17	15.1	7.59	4.40	57.9	...	...	...
12	7.59	1.17	15.4	7.53	4.09	54.3	...	...	...
15	7.67	1.06	13.8	7.53	4.33	57.5	7.52	5.32	70.7

Treatment with Steam at High Temperatures.

A few experiments were conducted by maintaining slag, contained in shallow boats at 1000° C., in an atmosphere of steam for 1 hr. Two size gradings of the samples were used, (a) between 10- and 25-mesh (B.S.S.), to give porosity, and (b) 100-mesh (B.S.S.). It was surmised that some fluorine might be removed by the superheated steam, but results were not sufficiently positive to encourage further investigation at the time. The author believes that if dry steam could be blown through liquid slag, removal of fluorine would result.

Pitside Experiments with Sodium Carbonate and Silica.

The foregoing work indicates that the most promising method involves the addition of sodium carbonate. It was decided, therefore, to carry out additions to low-solubility slags on a full scale in the pitside during tapping.

All slags are caught in standard Dewhurst ladles after overflowing the steel ladle, and consequently few difficulties were anticipated. Clean bowls were used in all trials. While the first few experiments were conducted with sodium carbonate alone, subsequent ones involved the use of a mixture of carbonate and silica in the form of common brown sand. The primary motive was to cheapen the addition by the use of a diluent which would, it was anticipated, have a similar effect. It was thought that the formation of some of the soluble silico-carnotite would be favoured if the silica content of the slag was increased, and since sintering experiments involving silica were obviously useless, this opportunity was taken to try its effect. It was also thought possible that by intimately pre-mixing the silica-carbonate mixture the former would be fluxed by the latter and so be assisted into true solution in the slag. This appears to happen, since no evidence of unfused sand has been found in any of the slags. The sodium carbonate used was I.C.I. granular, supplied in 2-cwt. bags. All materials were carefully dried, weighed and mixed before use, any caked material being crushed. Mixtures were weighed into 10-lb. bags, this unit weight being a convenient quantity to throw over the lip of a slag ladle from floor level from a reasonable distance. It was found that the maximum addition possible in the few minutes taken to fill the Dewhurst ladle was 800 lb., four men being employed. A conical steel bin with a controllable bottom opening, suspended by the auxiliary hoist over the slag ladle, would have been preferable.

In all experiments the slag remained molten after the additions—

apart from a thin top crust. White fumes were evolved during the additions, and some little material was carried away by the fierce convection currents. The amount appeared negligible. No change was visible in any of the slags after cooling. During the experiments no addition of moist earth or rubbish for "boiling down" the slag was permitted, but the action of the sodium carbonate appeared, conveniently, to have the same effect.

Slow-cooled spoon samples * were in all cases drawn from the furnace just at tapping, and the solubility of these samples formed the basis on which the improvement due to treatment was assessed. The sampling of the treated slags presented a problem, in that it was not always convenient to tip "liquid," and the identification and sampling of solid "balls" is difficult. Liquid tipping also involved possible contamination from previous slags and there was no way of inserting a spoon. The method of sampling adopted was to immerse a long "poking-out" rod from stage level to a depth of 3-3½ ft. This was agitated from side to side in the ladle, withdrawn, and the slag coating allowed to cool. The slag was then chipped off along the whole length, and crushed, quartered and sampled.

In view of the known effect of quenching from the liquid, some doubt arose as to whether sampling by chilling on a rod would alter the solubility seriously. This point was investigated and the values in Table VI. were obtained.

TABLE VI.—*Effect of Sampling Method on Solubility Value—Cast P9924.*

Sample No.	Time.	Sample Condition.	Total P_2O_5 %.	Soluble P_2O_5 %.	Solubility %.
1	12.20 P.M.	Standard sample, slow-cooled spoon (outside furnace).	10.29	2.50	24.5
2	12.24 P.M.	Red-hot rod immersed in slag (inside furnace) for 30 sec., withdrawn, air-cooled.	9.91	3.05	30.8
3	12.22 P.M.	Cold rod immersed in slag (inside furnace) for 30 sec., withdrawn, air-cooled.	10.23	3.18	31.0

As a result of the rod method of sampling the solubility value is raised by some 6%, approximately. When the slag is tapped in the liquid condition, however, the rod sample appears to be truly representative of the solubility (see Table VII.).

TABLE VII.—*Different Samples from a Treated Slag—L657.*

Sample Condition.	Total P_2O_5 %.	Soluble P_2O_5 %.	Solubility %.
Slow-cooled spoon, before treatment	8.50	1.30	15.3
Treated slag, rod sample from Dewhurst ladle	9.17	3.08	33.7
Treated slag, Slag-hill sample, after tipping liquid	8.80	2.88	32.8

It is concluded that discrepancies due to rod sampling are not serious when determining the effect of a treatment. Tipping from liquid conditions, which tends to have the same effect as rod sampling, is in most cases desirable.

* This sample was taken as standard throughout the work. The spoon is 4 in. in dia. by 2½ in. deep and is filled with slag, withdrawn, and allowed to cool in air on the stage. The whole contents are crushed and quartered down.

Complete results for the full-scale treatments are given in Table VIII.

TABLE VIII.—*Results for Full-Scale Treatment.*

Experiment No.	Charge No.	Weight of Spar.		Ladle Additions.		Estimated Weight of Slag, Tons. ²	Additions per Ton of Slag (approx.). ³		Total P ₂ O ₅ . ⁴ %	Soluble P ₂ O ₅ . ⁴ %	Solubility. ⁴ %	Gain. Solubility Units.
		Recorded. Cwt.	Probable. ¹ Cwt.	Na ₂ CO ₃ . Lb.	SiO ₂ . Lb.		Na ₂ CO ₃ . %	SiO ₂ . %				
16	M9571	5	1	616	Nil	5.0	5½	Nil	9.60	4.37	45.5	...
6	O9540	1	1	200	600	6.0	1½	4½	9.60	6.09	63.5	1.72
12	N9894	5	4	448	400	8.5	2½	2	6.94	4.19	60.4	...
13	N9895	7	5	448	400	5.0	4	3½	7.32	5.26	71.9	1.07
1	N9718	4	6	100	300	8.0	½	1½	7.57	2.27	30.0	...
2	N9670	6	7	400	Nil	6.0	3	Nil	7.57	4.49	59.3	2.22
17	M9573	7	7	672	Nil	8.5	3½	Nil	9.79	1.84	18.8	...
5	O9538	8	7	200	600	5.0	1½	5½	9.72	5.05	51.9	3.21
10	N9888	10	7	224	600	8.5	1½	3½	7.90	1.79	22.7	...
11	O9554	8	8	448	400	6.0	3½	3	7.51	3.10	41.3	1.31
4	L657	10	8-9	200	300	7.0	1½	2	10.38	1.47	14.2	...
14	N9897	13	9	448	400	8.5	2½	2½	10.36	3.56	34.4	2.09
7	M9551	11	9-10	224	600	8.5	1½	3½	7.60	1.44	18.9	...
8	N9885	9	10	224	600	8.5	1½	3½	7.63	2.40	31.5	0.96
9	P9939	9	10	224	600	8.5	1½	3½	8.77	1.44	16.4	...
18	M9575	7	10	448	400	6.0	3½	3	8.55	3.75	43.8	2.31
3	O9375	7	11	80	720	8.0	½	4	7.94	1.44	18.1	...
15	O9563	10	13	448	400	6.0	3½	3	7.40	2.49	33.7	1.05
									9.66	1.38	14.4	...
									8.72	3.81	43.7	2.43
									8.50	1.30	15.3	...
									9.17	3.08	33.6	1.78
									8.44	1.23	14.6	...
									7.92	2.49	31.4	1.26
									7.66	1.13	14.7	...
									7.54	2.43	32.2	1.30
									7.21	1.11	15.4	...
									7.22	2.40	33.2	1.29
									6.34	1.04	16.4	...
									6.12	2.58	42.1	1.54
									6.58	1.04	15.8	...
									6.58	3.63	55.2	2.59
									7.76	0.98	12.6	...
									7.29	2.16	29.6	1.18
									7.63	0.86	11.3	...
									7.70	3.60	46.7	2.74

¹ See Fig. 3.

² Low values.

³ High values.

⁴ Figures for before and after treatment given.

Interpretation of the results obtained quantitatively presents considerable difficulty. The quantity of spar added to the furnaces varied over a wide range and, unfortunately, it was not possible to weigh the ladles of slag, owing to dislocation of traffic thereby. Hence, the only means for estimating the quantity was by noting the volume in the ladles. Estimates of the weights have been incorporated in Table VIII., and have been kept purposely low (10-20%) in order to arrive at a "safe" estimate for the cost of the additions "per ton." The ladle bowls used have a capacity of 240 cu. ft., and finishing slags have powder densities (100-mesh B.S.S.) of the order of 3.2-3.5. This should give a liquid capacity of 17 tons. Owing to the evolution of gases during cooling, and to solidification shrinkage, the liquid capacity is much less than this, say, 12-13 tons.

Early results appeared confusing and the treatment effects were difficult to correlate. Consequently, it was not until a larger number of results had been accumulated that tentative explanations could be advanced.

has been shown to be so by Gibson* for high-initial-solubility slags, repeated applications of the acid extracting diminishing quantities of P_2O_5 until none remains. The figures in Table X. were obtained during the present work with a slag of the low-initial-solubility type. In this case the amounts of P_2O_5 extracted during each application of acid appear to be nearly constant, a rapid diminution occurring only near the end.

If there is insufficient fluorspar in the slag to bond all the P_2O_5 as fluorapatite, then normal phosphates and silicophosphates coexist with the apatite. The silicophosphate, $5CaO.P_2O_5.SiO_2$, is almost completely soluble (96%) in citric acid, as is the compound $9CaO.P_2O_5.3SiO_2$. The normal phosphate ($3CaO.P_2O_5$) in the α form is stated to be 96.8% soluble.

The complexity of the fluorapatite molecule and its relatively small fluorine content explains why only small amounts by weight of spar are necessary to reduce so drastically the citric-acid solubility of a slag.

In view of the above it is suggested that the ideal solubility curve for any particular slag of known P_2O_5 content is as shown in Fig. 3. It may be

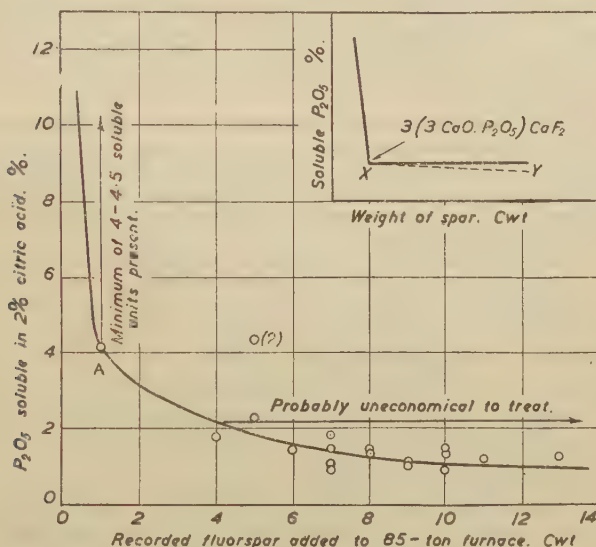


FIG. 3.—Effect of Fluorspar Additions on Solubility.

that, over the portion XY , which covers excess additions of spar over the amount necessary to satisfy the composition requirements of the fluorapatite, the solubility decreases very slightly still further, owing to the presence of increasing "free" CaF_2 . That such is actually the case is indicated by the trend of the values for percentage of soluble P_2O_5 for all the untreated slags in Table VIII (see also Fig. 3).

Based upon this trend, Table VIII. includes an estimate of the probable spar additions, and they agree reasonably well in general order of magnitude (with one exception) with those actually recorded and plotted in Fig. 3. Spar additions recorded by the melters are nominal and not necessarily accurate, since weighing was not carried out. While it is unfortunate that one value (experiment 16, Table VIII.) falls well away from the general

* Private communication.

curve, it does not seriously prejudice the remaining results. In one case (point A, Fig. 3) the weight of spar was definitely known, and the trend of the remainder of the points—including experiment 16—does show that, beyond some spar addition which gives a low solubility value, additional increases of spar do decrease the percentage of soluble P_2O_5 still further.

As a result of this arrangement of the soluble- P_2O_5 values, together with the corrected weights of spar added, the curve in Fig. 3 becomes an average one for the range of total P_2O_5 contents occurring in these slags, and is made up of a series of overlapping curves (of the ideal form given in the inset), each belonging to a particular slag.

The improvement in the solubility brought about by treatment with sodium carbonate, either added to the liquid or sintered with the solid slag, can be attributed to the replacement of the calcium atom in the bonded fluoride by the sodium atom, with the liberation of carbon dioxide. From the results obtained with various sodium salts, dissociation of the added salt must occur at high temperatures, in order to liberate the active sodium ion. The suggestion is made that sodium chloride fails, and the sulphate and hydroxide are only partially effective, because the first does not dissociate, while the latter do so to a lesser extent than the carbonate. In this connection it is interesting to note that an early pitside experiment in which crushed fused borax was added to a liquid slag resulted in no improvement. It had been hoped that some fluorine would be removed by the boron, but results were quite negative, indicating that no dissociation had taken place. In the light of the more recent work the result would have been expected, since the stability of borax glasses at high temperatures is well known. Further experiments with this material were ruled out on account of prohibitive costs.

While it seems probable that the added sodium preferentially replaces excess CaF_2 first, and then partially the bonded CaF_2 , to give some (or all) $3(3CaO.P_2O_5).2NaF$, the evidence is not clear. If excess CaF_2 is first replaced, one would expect that the increase in solubility (for any particular addition of sodium) should be lower, the lower the initial solubility. Conversely, if the solubility is fairly high, indicating little or no excess CaF_2 , then the gain in solubility on treatment should be greater. Inspection of the results contradicts this, since the gain in solubility appears to be greater after treatment the lower it is initially, and efficiency falls off as the initial solubility increases (Fig. 2).

While this evidence is conflicting, the preference of the sodium for the excess CaF_2 , in the first place, is supported by the experiment described below. If free sodium fluoride (from excess CaF_2) is formed, then it should be possible to extract fluorine in a water-soluble form. This has been done by shaking samples of sieved slag (100-mesh B.S.S.), rendered completely soluble by sodium carbonate treatment, with distilled water, filtering and evaporating to dryness, and testing for fluorine in the residue by the hanging-drop test.⁽⁴⁾ The quantitative determination of fluorine is extremely difficult, and no satisfactory method has been evolved in the author's laboratory. Colorimetric methods, thought to be promising, have been found formidable, owing to the numerous interfering factors. The qualitative test applied, however, gave positive results in several instances.

The present work is by no means adequate to explain the mechanism precisely. It may be that the bond between the fluorine and the calcium phosphate molecule is loosened and the entity of the fluorapatite destroyed. If, however, the replacement theory holds good, then a definite indication is given that the excess CaF_2 should be reduced to a minimum before treatment with sodium carbonate produces maximum efficiency. For this

reason the curve in Fig. 3 has been marked off to indicate the probable profitable limits for treatment, *i.e.*, in the vicinity of its sudden change in direction (1–4 cwt. of spar for an 85-ton furnace). Since spar, when used, is often applied generously, control of its addition should render possible a commercial treatment.

The function of the silica in contributing towards increased solubility appears more complicated, but it is probable that the tendency towards the formation of silicophosphates is enhanced. Its action in rendering the phosphates in a slag less stable is well known. On this assumption, owing to the relative proportions of silica in the silicocarnotite, greater additions by weight are necessary to obtain an increase equivalent to that obtainable with the carbonate. Experimental results indicate that it is a useful diluent in reducing the cost of treatment.

Acknowledgments.

The author expresses his thanks to Sir John Craig, C.B.E., and Dr. A. McCance, F.R.S., Directors of Messrs. Colvilles, Ltd., for permission to publish this work, and also for suggestions. He records also the valuable assistance received from his laboratory staff and the melters and casting-bay men of No. 2 melting shop, who responded to his demands with a very good will.

REFERENCES.

- (1) "Statutory Rules and Orders," pp. 492–496, 501, Fertilisers and Feeding Stuffs Regulations. London, 1932: H.M. Stationery Office.
- (2) LATHE: *Journal of the Society of Chemical Industry*, 1943, vol. 62, Feb., pp. 24–28.
- (3) WHITE: *Journal of The Iron and Steel Institute*, 1943, No. II., p. 579 p.
- (4) SCOTT and FURMAN: "Standard Methods of Chemical Analysis," fifth edition, vol. 1, p. 400. New York, 1939: D. Van Nostrand Company.

CORRESPONDENCE.

Mr. F. E. LATHE (National Research Council, Ottawa, Canada) wrote: Mr. Pearson refers in his interesting paper to work carried out at Sydney, Nova Scotia, as reported in the *Journal of the Society of Chemical Industry* for February, 1943. The experiments in question were made in co-operative studies of the slags of the Dominion Steel and Coal Corporation carried out by a committee set up for the purpose. Since the committee's work has advanced considerably in the past two or three years, it may be of interest for me to comment on Mr. Pearson's paper in the light of recent experiments in Canada.

Mr. Pearson found that the average citric-acid solubility of the phosphoric acid in three open-hearth finishing slags was increased from 13.2 to 30.4% (Table III.) by quenching in water, as compared with cooling in a small spoon. He concluded that "the increase in solubility possible by this method is limited." He subsequently reported (Table IV.) an increase from 22.6 to 60.8% in another test.

These results are in line with those obtained at Sydney by similar methods, except that our rates of cooling have now covered a much wider range. At one extreme, the slag was allowed to solidify very slowly in boxes holding several tons. The time required for solidification is unknown, but even after two or three days the slag was too hot to handle comfortably. It was also found that the solubility of the phosphoric acid in such material was often substantially lower (38.6% in the case of one slag containing no fluorspar) than in those cooled in spoons or small

test boxes. My paper reported on a quenched slag in which the - 3/+ 10-mesh portion had a solubility of only 20.86%, as compared with 42.00% for the 100-mesh portion. More recently, Dr. N. A. D. Parlee at Sydney has similarly tested finishing slag quenched by a commercial method, in which the falling stream of slag was broken up by a jet of steam. The corresponding figures were 41.8% for the + 6 fraction and 68.0% for the - 100 mesh. The same slag cooled in a test box had a solubility of only 12.8%. Microscopic examination of this slag by Parlee showed that, when slowly cooled, it had a coarsely crystalline structure, but that in the quenched slags the grain size decreased rapidly as the fractions became finer. In the - 80/+ 100-mesh fraction it was barely possible to resolve the grains at a magnification of 600 diameters.

As a result of many such tests, the committee has become fully convinced that rapidity of cooling is the most important single factor governing the phosphoric-acid solubility of any given slag. It is the writer's personal opinion that, by the use of a jet of high-pressure water to break up a falling stream of molten slag, the solubility can be raised from 10-15% to 65-75%, and this at extremely low cost. In view of the above, one should not accept hand-quenching—as reported both by Mr. Pearson and by the writer—as even approaching in effectiveness what can be done by commercial means. On the other hand, sampling with a rod or spoon cannot be accepted as equivalent to very slow cooling.

Mr. Pearson's experiments with sodium carbonate are most interesting, even though, as he points out, the cost of such treatment would be prohibitively high for commercial operation. His explanation of the action of sodium compounds may be correct, and it is hoped that experimental evidence on this point may be sought. One would scarcely expect sodium chloride to be effective, since chlorapatite is readily formed, and all apatites investigated are of low solubility in citric acid.

Mr. Pearson refers to his Fig. 2 as evidence that the efficiency of soda treatment falls off as the initial solubility increases. This is only apparent, for Fig. 2 shows only the *percentage* increase in solubility (or "decrease of 'insolubility' %," as he calls it), rather than absolute increase. Actually, considering all tests listed in Table VIII., the average absolute increase in solubility is 1.83 for six slags having an initial solubility of less than 15%, 1.84 for eight slags between 15 and 20%, and 1.58 for the four above 20%. These differences are far from being statistically significant; one slag having an initial solubility of 30% showed an increase of 2.22.

Mr. Pearson states that "the function of silica in contributing towards increased solubility appears more complicated." The writer believes that, generally speaking, apatite formation occurs rapidly when fluorine exists in a molten slag in the presence of more than sufficient lime to combine with all the phosphoric acid as tricalcium phosphate and all the silica as dicalcium silicate. The action of silica is to displace fluorine from its combination with calcium, and thus break up the apatite structure, but, as many experiments here have indicated, this will not occur to any considerable degree while lime exists as tricalcium silicate, dicalcium ferrite, or tetracalcium aluminoferrite, hence the lime in all of these compounds must first be satisfied.

No experiments have been carried out at Sydney with the object of increasing the solubility of the phosphoric acid by additions of silica. However, Parlee has observed that the "residual" slag which remains in the steel ladle after teeming is higher in silica and availability of phosphoric acid, but lower in total phosphoric acid and fluorine, than is the corresponding "overflow" slag quenched immediately after tapping. The change in composition is due to attack of the slag on the ladle lining

during the considerable period which always elapses before the teeming of the steel is complete. An average of the quenched slag produced from three heats gave the results shown as follows :

Type of Slag.	SiO ₂ , %.	CaO, %.	P ₂ O ₅ .		Percentage Available.
			Total, %.	Soluble, %.	
Overflow	13.75	48.85	8.93	4.15	46.7
Residual	14.77	46.90	7.89	6.43	81.7

Taking into consideration all the information available to date, it would appear that the most economical method of increasing the solubility of open-hearth tapping slag containing fluorine is to prevent the formation of the apatite structure by quenching it as rapidly as possible, and that, at least in some instances, further substantial improvement in solubility can be effected by increasing the acidity of the slag by the addition of silica or clay prior to quenching.

AUTHOR'S REPLY.

The AUTHOR wrote in reply : I thank Mr. Lathe for his most interesting contribution. It is apparent that the objectives in view are identical and the general conclusions reached appear the same. My statement (p. 443 P) that "the increase in solubility possible by this method (quenching) is limited" refers specifically to the pouring of small samples into water in a thin stream, and is based upon the general run of increased values obtained. The statement is therefore not intended to discount the subsequent statement that "the speed and severity of the quench determines the degree of improvement possible."

At Clydebridge we were interested in some simple method of quenching which would not entail appreciable cost, and for this reason steam was ruled out. Tipping the molten slag into shallow ponds was visualised, but it was decided that this was too dangerous, since there is occasionally the possibility of some liquid steel overflow from the steel ladles being present. It is actually possible to pour large masses of liquid slag into water without obtaining, necessarily, a severe quench, since the heat content of the slag is so great. Consequently, extremely intimate contact of the quenching medium and slag is necessary. Mr. Lathe's remarks concerning the use of steam by Parlee are therefore appreciated, and it is noted that even with this quench there is a difference in solubility depending upon the size of product resulting—the finer giving the higher solubility value.

With reference to the falling-off in efficiency of increased sodium carbonate additions, this work is by no means complete, but I believe that the statement made would be substantiated if all slags had the same silica content. The function of the silica is not perfectly clear to myself, but Mr. Lathe's suggestion—that the action of silica is to displace fluorine—is noted.

Subsequent to the work described in the paper we have found, in the presence of fluorine, phosphorus, sodium and lime, that increasing silica may actually decrease the solubility of the product in citric acid, while decreasing quantities in the presence of increased sodium have the opposite effect. These results emerged from a study of the "synthetic silicophosphate" which was made on the Continent before the war. The process was carried out by calcining natural rock phosphate with soda and silica. Our own experiments were carried out by the comparatively low-temperature sintering (1050° C.) of a rock phosphate high in fluorine (most

phosphates within easy reach of the British Isles appear to be high in fluorine, unfortunately) and the results are given in Table A. There are slight discrepancies in the diluent effect of the additions, owing to the use of small distinct batches of materials, but the general trends of the values are significant.

TABLE A.—*Sintering of Rock Phosphate with Soda and Silica.*

Rock Phosphate.	Additions by Weight, %.		P ₂ O ₅ .		
	Na ₂ CO ₃ .	SiO ₂ .	Total, %.	Soluble, %.	Solubility, %.
As received.	Nil	Nil	33.82	10.94	32.4
Calcined (1000° C.).	Nil	Nil	34.26	1.39	4.5
As received.	1	Nil	30.97	1.90	6.15
	3	Nil	30.79	2.49	8.08
	5	Nil	30.23	3.53	11.66
	7	Nil	30.16	5.40	17.92
	10	Nil	29.48	7.83	26.60
	15	Nil	29.40	13.22	44.90
	2	4	31.80	2.65	8.30
	2	9	29.20	2.21	7.60
	2	14	24.95	2.26	9.00
	2	19	21.43	1.74	8.10
	2	24	17.80	1.57	8.80
	5	5	31.80	3.95	12.40
	5	15	27.38	2.55	9.30
	5	25	25.00	2.10	8.35
	5	35	20.62	1.92	9.30
	5	45	17.11	1.39	8.10
	10	5	29.48	12.49	42.5
	10	7	29.98	11.00	36.8
	10	10	28.30	3.06	10.8
	15	5	27.0	19.52	72.0
	15	7	26.0	18.70	71.8
	15	10	26.42	15.80	59.6
	20	Nil	26.88	14.80	55.0
	20	5	26.20	23.60	90.0
	20	7	26.40	23.20	87.7
	20	10	25.74	21.50	83.5
	25	Nil	25.44	17.48	68.8
	25	5	25.10	24.50	97.2
	25	7	24.80	24.20	97.0
	25	10	24.40	24.18	98.5

The effect of calcining without additions in converting the initially hydrated mineral to the almost completely insoluble tricalcium phosphate is shown, and the statements previously made regarding the effect of silica are borne out. None of these sinters showed any appreciable water solubility, and it was concluded therefore that sodium phosphate is not formed to any extent. To us, therefore, the precise function of silica is not yet clear, and further work is necessary to elucidate it.

The values given by Mr. Lathe for the solubility of residual ladle slags are noted and their trend has been confirmed in our own case.

AN X-RAY STUDY OF IRON-RICH IRON-SILICON ALLOYS.*

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(Figs. 2 and 3 = Plates XLIV. and XLV.)

SYNOPSIS.

Although much work on the iron-silicon system has been done in the past, there are still several problems connected with it that need solution. The present paper describes some experimental work, by X-ray diffraction methods, on the iron-rich part of the system. This work has confirmed the main outlines of the α phase boundary found by previous workers, but has placed it on a firmer foundation by the use of data from more alloys. At temperatures between 1030° and 1195° C. the phase boundary has been modified by the discovery of a new phase, α'' , which calls for some modification of the equilibrium diagram. The reaction by which α'' is formed is unusual, and is discussed in some detail; by consideration of free-energy principles it is concluded that the reaction is either polymorphic or peritectic, but not peritectoid.

An interesting relationship has also been found between the orientations of the η phase and the α matrix in which it is precipitated; on the basis of this a reason is advanced for the precipitation of η outside its range of stability. The precipitation of η instead of ϵ has been observed particularly in commercial alloys.

INTRODUCTION.

THE iron-silicon system is one that lends itself well to study by X-ray methods for two reasons; first, the solution of silicon in ferrite causes a rapid decrease of cell dimension,¹ so that the phase boundary can be accurately determined by standard methods,² and, secondly, the various phases that occur give powder patterns that are easily distinguished from each other and so provide a reliable method of deciding which phases are present in any alloy. The particular importance of this will be shown in later sections.

The iron-silicon system, as described in the 1939 edition of the "Metals Handbook,"³ presents several interesting problems, some of which we have attempted to solve. In addition, the system has a practical interest in that alloys containing about 15% of silicon are greatly used in the chemical industry because of their acid-resisting properties. The correct annealing treatment is of importance because of the tendency of the alloys to become internally stressed, and so naturally an exact knowledge of the equilibrium diagram is required in order that the stress-relieving treatment shall not result in the precipitation of unwanted phases.

EXPERIMENTAL.

The alloys used for this work were obtained from three different sources. Six binary iron-silicon alloys, SE 10, 14, 15, 16, 17, and 20, were received from the National Physical Laboratory. The alloys were made from iron of at least 99.95% purity, and silicon of 99.7-99.8% purity, in an H.F. induction furnace *in vacuo*. The analysis of all these alloys, except SE 20 which was analysed at the N.P.L. and found to contain

* Received July 17, 1945.

19.51% of silicon, was kindly carried out for us by Mr. E. W. Colbeck, of Imperial Chemical Industries (Alkali Division), and the results are given in Table I. Mr. Colbeck also prepared four binary alloys *in vacuo* in an H.F. induction furnace and subsequently analysed them. In addition, we have made several alloys from Hilger Iron No. F 693 (99.97% of iron) and silicon of purity 99.80%; they were melted in an H.F. induction furnace under a small pressure of hydrogen, which was pumped off when the melting was complete. Analysis was carried out by Mr. Colbeck by means of a bromine/hydrobromic-acid reagent,⁴ and the results are given in Table I.

The alloys were homogenized by annealing at 1000–1100° C. *in vacuo* for about 3 or 4 days. The lumps were then crushed in a hardened-steel percussion mortar until fairly fine powder was obtained. For further heat-treatment the powder was placed in silica tubing of 1 mm. bore, which was evacuated and sealed off.

THE PHASE DIAGRAM.

The equilibrium diagram based on present results is shown in Fig. 1. It is confined to that part of the system between iron and FeSi (33.4% of silicon), as it is only in this region that we have made any changes from Stoughton and Greiner's diagram in the "Metals Handbook."³

The most important part of the diagram is the extended solid solution of silicon in iron. This terminates at about 15% silicon, to be followed by a two-phase region ($\alpha + \epsilon$), ϵ having the composition FeSi. At higher temperatures another phase, η , of composition Fe₅Si₃ occurs; it is produced by a peritectoid reaction at 1030° C. and dissociates again by a eutectoid reaction at 825° C. This is rather an unusual feature in an equilibrium diagram, but its truth seems to be fairly well established.

We have, however, also found that another phase, α'' , exists at higher temperatures. We have not been completely successful in establishing its mode of formation or dissociation. The details shown in Fig. 1 are certainly not complete, but are an expression of purely experimental results; we shall attempt to show that they are not completely implausible.

These are all the solid phases that we shall consider. We must also point out that we have not made any attempts to redetermine any of the reaction temperatures; these are taken from the work of Haughton and Becker.⁵

The α Phase Field.

The α phase field consists of a solid solution of silicon in iron. The structure is body-centred cubic and its X-ray powder photograph is shown in Fig. 2(a). At low percentages of silicon there is obviously a random distribution of iron and silicon atoms, but, as the percentage of silicon increases, ordering takes place, as shown by the appearance of superlattice lines (Fig. 2(b)). The superlattice is similar to that which occurs in the alloy Fe₃Al.⁶

This ordering is first noticeable on X-ray powder photographs of an alloy containing 6.7% of silicon. Since the ordering is similar to that of the atoms in Fe₃Al, one would expect the ideal composition of the ordered structure to be Fe₃Si. Some discussion has taken place as to whether Fe₃Si should be regarded as an intermetallic compound, and Yap⁷ has found a discontinuity in the electrode potential at this composition. By analogy with Fe₃Al, however, there is no reason to suppose that there is anything peculiar about this composition, except that the ordering is complete. If more silicon is added, the alloy being maintained as a single phase by quenching from a high temperature, the ordering continues

exactly as in the iron-aluminium system. This is manifested by a decrease in intensity of the first superlattice line, 111, and an increase of the second, 200. This phenomenon has been noticed by Osawa and Murata,⁸ who thought that it signified the existence of another phase field, α'' ,

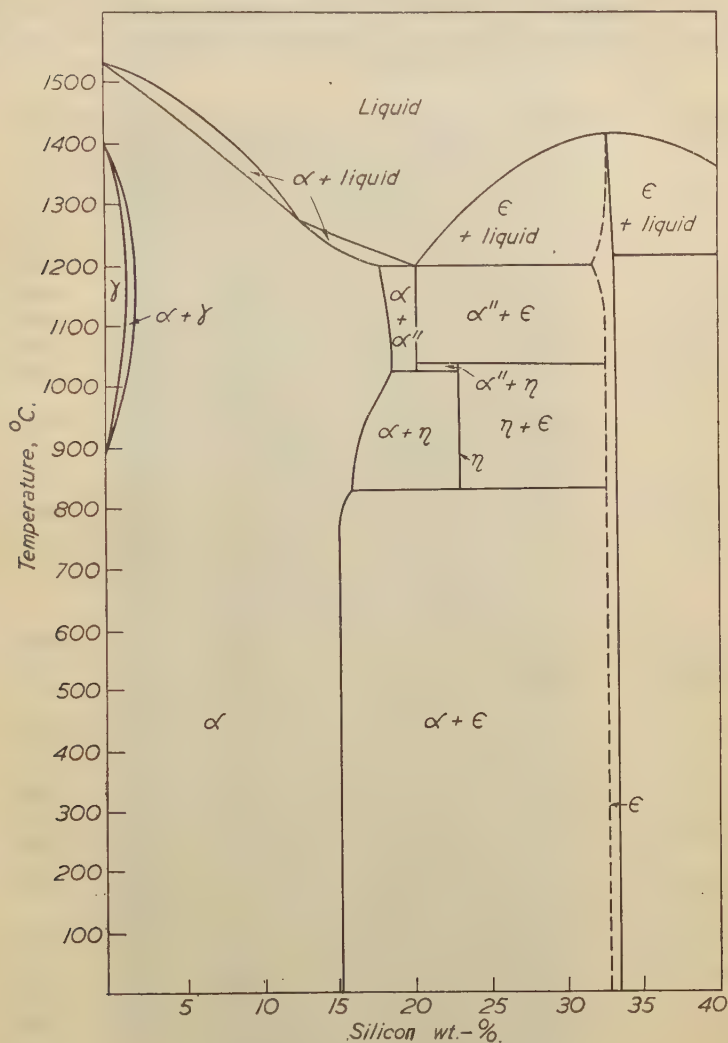


FIG. 1.—The Iron-Silicon Equilibrium Diagram.

but there is no reason why this should be so. They claim to have found a two-phase field separating the different superlattice structures, but there is no evidence for this in our results, although it would explain the peculiarity in the solidus and liquidus curves.⁵

With solution of silicon in iron there is a marked shrinkage of the lattice. The variation of lattice parameter with composition was first investigated by Phragmén,¹ although he used very few alloys. Jette and Greiner,⁹ however, used many more alloys in their investigation and we have used still more. In particular we have obtained data for alloys containing between 15% and 18% of silicon, as this region is especially important for the determination of the α phase boundary; Greiner and Jette¹⁰ have relied upon extrapolation of the lattice-parameter curve

TABLE I.—*Compositions and Lattice Parameters of Single-Phase Alloys.*

Alloy.	Silicon, wt.-%. I.C.I. analysis, unless otherwise stated.	Silicon, at.-%. Calculated, unless otherwise stated.	Lattice Parameters, kX.	
			Measurements at 19° ± 1° C.	Mean.
Hilger F 693	99.7% Fe	—	2.8604	2.8604
2.5 At.-%	1.29 Calc.	2.5 Nominal	2.8591	2.8591
5 At.-%	2.57 Calc.	5.0 Nominal	2.8575	2.8575
7.5 At.-%	3.98 Calc.	7.5 Nominal	2.8556	2.8556
10 At.-%	5.82	10.5	2.8533 2.8530 2.8532	2.8532
12.5 At.-%	6.84	12.75	2.8461 2.8461 2.8462	2.8461
15 At.-%	8.12	14.95	2.8429 2.8429 2.8431 2.8427	2.8429
SE 10 N.P.L.	9.70	17.61	2.8371 2.8369 2.8371 2.8369	2.8370
20 At.-%	10.76	19.35	2.8325 2.8328 2.8327 2.8326 2.8328 2.8328 2.8327	2.8327
11.5 I.C.I.	11.95	21.26	2.8291 2.8292	2.8291
SE 14 N.P.L.	13.95	24.39	2.8226 2.8227 2.8228 2.8225	2.8226
25 At.-%	14.10	24.62	2.8216 2.8219 2.8219 2.8218 2.8218	2.8218
14.5 I.C.I.	14.50	25.23	2.8206 2.8207 2.8207	2.8207
SE 15 N.P.L.	14.88	25.81	2.8189 2.8189 2.8190 2.8189	2.8189
SE 16 N.P.L.	15.70	27.04	2.8164 2.8163 2.8163 2.8163	2.8164
SE 17 N.P.L.	16.65	28.45	2.8129 2.8129 2.8129	2.8129
30 At.-%	16.98	28.93	2.8124 2.8124 2.8124	2.8124
18.5	18.00	30.40	2.8101 2.8098 2.8101 2.8099 2.8102	2.8100
18.5 I.C.I. Homogenized	18.25	30.76	2.8092 2.8092	2.8092
18.5 I.C.I. Not homogenized	18.45	31.04	2.8077 2.8076	2.8076



FIG. 2A (see Fig. 2B).—The Iron-Silicon System : X-Ray powder photographs taken in a 19-cm. camera with $\text{CoK}\alpha$ radiation.

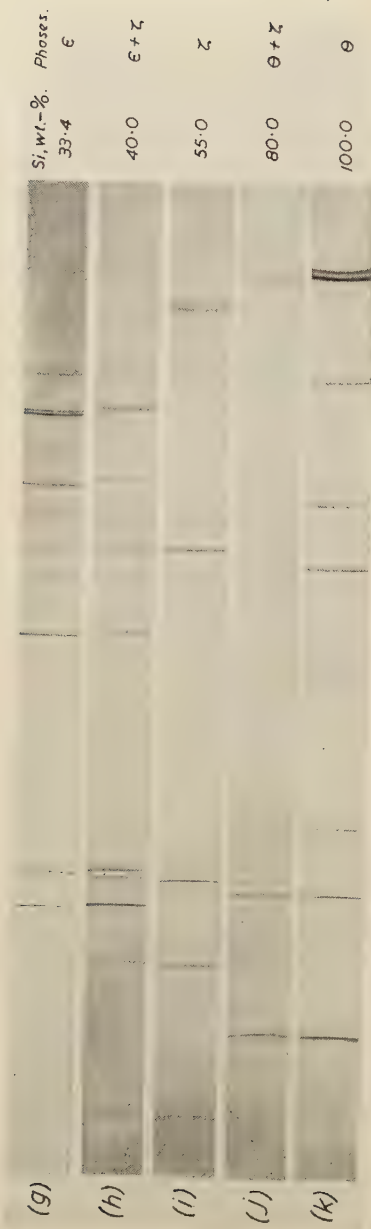


FIG. 2b (see Fig. 2a).—The Iron-Silicon System : X-Ray powder photographs taken in a 19-cm. camera with CoK_α radiation.



FIG. 3.—X-Ray Powder Photograph of an Iron-Silicon Alloy containing 19.95% of silicon and showing two α -phases.

between 5% and 15% of silicon to obtain these data, and, as Hume-Rothery and Raynor¹¹ point out, this practice may lead to errors.

X-ray powder photographs were taken in a 19-cm. camera adapted so that the van Arkel film mounting could be used. In this way the high-angle reflections were recorded on one piece of film instead of on two as in the usual method with 19-cm. cameras. This should result in greater accuracy.¹² CoK (unfiltered) radiation was used for alloys of silicon content lower than 5.28%; CrK (unfiltered) radiation for alloys between 5.28% and 16.65% of silicon; and FeK (unfiltered) radiation for those of higher silicon content. In this way a line was obtained with a Bragg angle as near to 90° as could be recorded conveniently on the film, thus ensuring a similar accuracy over the whole range of composition studied. FeK radiation was used in addition to CrK for the two alloys containing 10.76% and 14.10% of silicon, because with these alloys the reflections with chromium were really too broad for accurate measurement. The reflections obtained with FeK radiation always seemed to be sharper than with CrK, presumably because CrK_α is a closer doublet than FeK_α , and were therefore much easier to measure. More than one photograph was taken of most specimens and each photograph was measured at least twice. Table I. gives the lattice parameter, a_n , of alloys with atomic percentage n of silicon and the plot of these consists of two straight lines. Between 5% and 18% of silicon this relation can be expressed as :

$$a_n = 2.8748 - 2.528 \times 10^{-6}n \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The weight per cent. plot (Fig. 4) between the same compositions may be expressed as :

$$a = 2.8769 - 4.56 \times 10^{-8}n + 4.5 \times 10^{-6}n^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The calculated and observed values of a_n for compositions expressed as atomic and weight percentages of silicon are compared in Table II.

It will be seen that some of the differences between calculated and observed lattice parameters in Table II. are considerable. We estimate that our values should not be in error by more than 0.0003 kX., and therefore the differences are unlikely to be due to experimental error; they must be due either to errors of analysis or in the fitting of the curves to the results. The smaller errors in the fitting of a straight line to the atomic-percentage results suggests that this is a closer approximation than the

TABLE II.—Comparison of Calculated and Observed Lattice Parameters.

Silicon Content.		Lattice Parameters, kX.				
At.-%.	Wt.-%.	Observed.	Calculated by Equation 1.	Differences, $\times 10^4$.	Calculated by Equation 2.	Differences, $\times 10^4$.
10.50	5.82	2.8532	2.8522	— 10	2.8519	— 13
12.75	6.84	2.8461	2.8473	+ 12	2.8478	+ 17
14.95	8.12	2.8429	2.8426	— 3	2.8428	— 1
17.61	8.70	2.8370	2.8369	— 1	2.8369	— 1
19.35	10.76	2.8327	2.8331	+ 4	2.8331	+ 4
21.26	11.95	2.8291	2.8290	— 1	2.8289	— 2
24.39	13.95	2.8226	2.8223	— 3	2.8221	— 5
24.62	14.10	2.8218	2.8218	0	2.8216	— 2
25.23	14.50	2.8207	2.8205	— 2	2.8203	— 4
25.81	14.88	2.8189	2.8192	+ 3	2.8191	+ 2
27.04	15.70	2.8164	2.8166	+ 2	2.8165	+ 1
28.45	16.65	2.8129	2.8135	+ 6	2.8135	+ 6
28.93	16.98	2.8124	2.8125	+ 1	2.8125	+ 2
30.40	18.00	2.8100	2.8094	— 6	2.8095	— 5
30.76	18.25	2.8092	2.8086	— 6	2.8088	— 4
31.04	18.45	2.8076	2.8080	+ 4	2.8082	+ 6

fitting of a parabola to the weight-percentage results. Even so, however, there are errors of the order of 0.001 kX., which would be equivalent to an error of 0.3% of silicon in the analysis. The accuracy we claim is equivalent to an error of less than 0.1% of silicon.

The lattice parameters of alloys containing less than 5% of silicon do not lie on the same curves as those of alloys containing more than 5%. This confirms the results of Jette and Greiner,⁹ who found that there was no single smooth curve that could be drawn through the whole range of points, but that two straight lines could be drawn when the composition was plotted in atomic percentages of silicon. No reason for this change in slope has yet been produced. Certain other examples have been ascribed to the electrons beginning to occupy a higher Brillouin zone,¹³ but in the present case uncertainty of the value of the electronic interchange between iron and silicon makes the calculation rather indefinite. It is more likely that the discontinuity in this case is due to the onset of order. The ordering of the silicon atoms is detected only at about 6.7% of silicon, but the superlattice lines are rather weak and so the first traces of order may not produce any obvious lines.

The coefficient of linear expansion of the alloy Fe_3Si was measured by taking X-ray photographs at elevated temperatures by means of the high-temperature camera designed by Wilson.¹⁴ The range of temperature covered was 22–700° C., as we wished to see if there was any abnormality at the Curie temperature (490° C.). The values of the lattice parameters, however, agree very well with the equation:

$$a_t = 2.8215_s + 3.27 \times 10^{-5}t + 1.95 \times 10^{-8}t^2$$

over the whole range of temperature; this can be seen from Table III., which gives a comparison of calculated and observed lattice parameters.

TABLE III.—*Variation of the Lattice Parameter of Fe_3Si with Temperature.*

Temp., ° C.	Lattice Parameters, kX.		Differences, × 10 ⁴ .
	Observed.	Calculated.	
22.0	2.8220	2.8223	+3
100.5	2.8254	2.8250	−4
200.9	2.8289	2.8289	0
300.2	2.8333	2.8331	−2
401.4	2.8376	2.8378	+2
499.0	2.8427	2.8427	0
601.6	2.8483	2.8483	0
650.7	2.8510	2.8511	+1
702.0	2.8543	2.8541	−2

It thus appears that there is no discontinuity at 490° C. The coefficient of linear expansion, α , deduced from the equation:

$$\alpha = \frac{1}{a} \cdot \frac{da}{dt}$$

may be expressed as:

$$\alpha = 1.16 \times 10^{-8} + 1.35 \times 10^{-8}t \text{ per } ^\circ \text{C.}$$

The agreement between the calculated and observed values of lattice parameter shown in Table III. supports our claim that the accuracy is in general better than 0.0003 kX.

The α Phase Boundary.

The α phase boundary was found by the usual quenching methods,² the results given in Table IV. being based upon the curve shown in Fig. 4.

TABLE IV.—*The α Phase Boundary.*

Silicon, wt.-%.	Quenching Temp., ° C.	Lattice Parameter, kX.	Composition of α , wt.-% Si.
16.98	slowly cooled	2.8185	15.05
16.98	560	2.8183	15.10
18.00	590	2.8186	15.00
16.60 *	700	2.8180	15.20
25.00 *	720	2.8184	15.10
18.00	825	2.8158	15.95
19.51	900	2.8141	16.45
16.98	930	2.8134	16.70
19.51	950	2.8118	17.2
19.51	1000	2.8081	18.45
20.0 *	1030	2.8089	18.20
20.0 *	1075	{ 2.8032	{ 20.15
20.0 *	1100	{ 2.8081	{ 18.45
20.0 *	1150	{ 2.8082	{ 18.40
20.0 *		{ 2.8023	{ 20.45
20.0 *		{ 2.8090	{ 18.15
20.0 *	1175	{ 2.8030	{ 20.2
20.0 *		{ 2.8087	{ 18.25
20.0 *	1175	{ 2.8030	{ 20.2
20.0 *		{ 2.8096	{ 17.9
19.51	1140	{ 2.8078	{ 18.53
		{ 2.8030	{ 20.2

* These percentages are those used in making the alloys; since exact compositions were not required for the determination of the α phase boundary, no analysis of the alloys has been made.

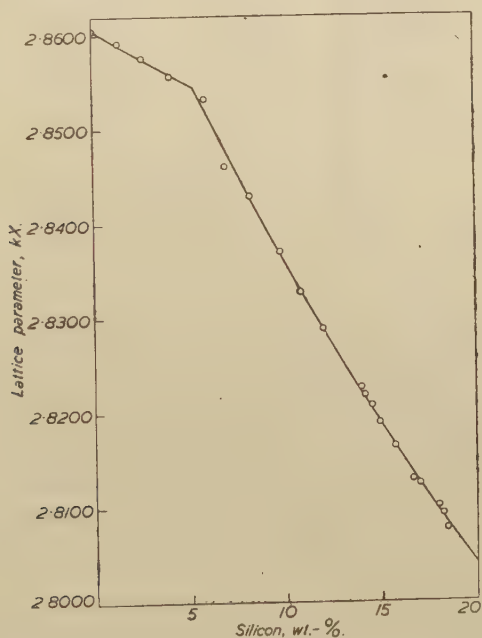


FIG. 4.—Variation of Lattice Parameter with Composition.

Fig. 5 gives the α phase boundary as deduced by us, together with those of Haughton and Becker⁵ and Greiner and Jette.¹⁰ It is generally realized that this method of obtaining the phase boundary is always subject to a certain amount of doubt;¹¹ but the agreement with the results of other workers at temperatures below 1000° C. provides a basis for believing that the results are not far from the truth.

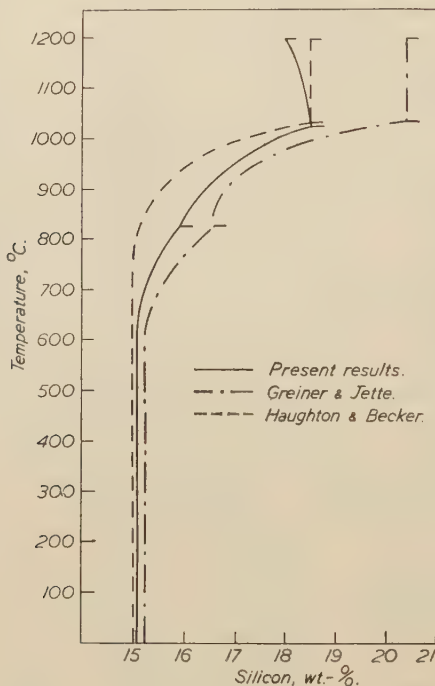


FIG. 5.— α Phase Boundaries.

The α'' Phase.

Alloys of about 19.5% and 20% of silicon were quenched from various temperatures above 1030° C. and were found to contain no η or ϵ phases. The α lines however were doubled, as can be seen in Fig. 3, indicating the presence of two phases of identical structure but different composition. Measurement of the lattice parameters showed that the composition of one phase was about 18.25% of silicon, while that of the other was greater than this. In order to determine the composition, the lattice-parameter/composition curve was extrapolated to about 21% of silicon. We consider that this is justified in view of the good agreement between the calculated and observed parameters given in Table II. The lattice parameter of the second phase corresponds to a composition of about 20.4% of silicon. On quenching alloys richer in silicon from the same temperatures, it was found that the α phase, although usually showing blurred lines, was single-phase and had a lattice parameter corresponding to that of the smaller of the two co-existing phases in the 19.5% and 20% silicon alloys. Data from several alloys after various heat-treatments show that

the composition of this second α phase is fairly constant at about 20.4% of silicon. Osawa and Murata⁸ have suggested the presence of another α phase having a maximum silicon solubility of 20.4%. They have called it α'' , and so, to avoid confusion, we are using the same notation, although the new phase does not appear to be identical with that of Osawa and Murata. It is worthy of note that Greiner and Jette¹⁰ also detected an α phase of silicon content 20.4% by weight, although they considered that there was continuous solubility of silicon in iron from 0 to 20.4% of silicon at 1030° C.

TABLE V.—*The α'' Lattice Parameters and Corresponding Compositions.*

Silicon, wt.-%.	Temp., ° C.	Lattice Parameters, kX.		Composition of α'' , wt.-% Si.
		a'' .	a .	
25 *	1075	2.8030	...	20.20
20 *	1075	2.8032	2.8081	20.15
25 *	1125	2.8031	...	20.15
20 *	1140	2.8018	...	20.65
20 *	1140	2.8023	...	20.45
20 *	1140	2.8022	...	20.50
25 *	1140	2.8021	...	20.55
25 *	1140	2.8021	...	20.55
25 *	1140	2.8020	...	20.55
27.5 *	1140	2.8019	...	20.60
27.5 *	1140	2.8032	...	20.15
23.1	1140	2.8017	...	20.65
23.1	1140	2.8016	...	20.70
19.51	1140	2.8027	2.8075	20.30
19.51	1140	2.8021	2.8085	20.55
19.51	1140	2.8030	2.8087	20.20
19.51	1140	2.8034	2.8087	20.05
19.51	1140	2.8029	2.8074	20.30
20 *	1150	2.8023	2.8090	20.45
25 *	1175	2.8034	...	20.05
20 *	1175	2.8030	2.8096	20.20
20 *	1175	2.8030	2.8087	20.20

* See footnote to Table IV.

Table V. gives the measured lattice parameters of the α'' phase measured from various photographs, together with the corresponding compositions obtained from the curve in Fig. 4. It would appear from the table that there is a range of composition of α'' of about 0.3% of silicon, but in some photographs the reflections were so broad that accurate measurement was impossible; the actual range of composition, if any, is therefore doubtful.

The introduction of a new phase into the equilibrium diagram necessitates the existence of another temperature horizontal near 1030° C., for, except by chance, the one temperature horizontal cannot be used for both the dissociation of α'' and the formation of η . On the basis of Haughton and Becker's⁵ results, we favour the form of diagram shown in Fig. 1, since, as Dr. Haughton has pointed out to us privately, the thermal-curve points on which they based the estimation of the temperature horizontal are lower on the iron-rich side than on the other. This observation is readily explained by our proposed diagram, in which the formation of η takes place at 1030° C. and the dissociation of α'' at about 1020° C.

The η Phase.

The η phase of the iron-silicon system was the only one whose structure was not worked out by Phragmén;¹ he described it as Fe_3Si_2 , containing
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HH

25.0% of silicon. This phase usually appears together with α or ϵ and the composition seems to correspond to 23–25% of silicon, but it is extremely difficult to obtain in a pure form. Greiner and Jette¹⁰ have shown that it is stable only between 825° and 1030° C. Our work supports this.¹⁵

In 1940 Osawa and Murata⁸ succeeded in indexing the lines on a powder photograph of η on the basis of a hexagonal unit cell with $a = 6.727$, $c = 9.411_2$ kX., and $c/a = 1.3989$, and suggested that the phase was really Fe_5Si_3 . We found, however, that if this unit cell is chosen no lines appear with l odd; this means that the c -axis is half the value put forward by Osawa and Murata. It was then realized that the unit cell was similar to that of Mn_5Si_3 . Comparative measurements of spacing as well as observation of intensities were carried out and the similarity was confirmed.¹⁶

The structure of Mn_5Si_3 was worked out by Åmark, Borén, and Westgren;¹⁷ the space group is $C6/mcm$ (D_{6h}^3). The unit cell contains $\text{Mn}_{10}\text{Si}_6$.

It is probable that the similarity of the two structures has been overlooked owing to the difficulty of deriving the right formula for the η phase. Borén¹⁸ studied, by X-rays, alloys of silicon with chromium, manganese, cobalt, and nickel. He observed the hexagonal phase in the manganese-silicon system, but did not remark on its similarity with the η phase of the iron-silicon system. He attributed to the manganese-silicon phase the formula Mn_3Si and to the iron-silicon phase the formula Fe_3Si_2 . It now seems certain that they should be described as Mn_5Si_3 and Fe_5Si_3 respectively.

The ϵ Phase.

The ϵ phase corresponds to the composition FeSi (33.4% silicon) and its X-ray powder photograph is shown in Fig. 2(g). The structure is cubic; Wever and Möller¹⁹ give the lattice parameter as 4.467 kX. and the unit cell contains four iron atoms and four silicon atoms. The space group is $P2_13$ (T^4), and the positions of the atoms are defined by two parameters u_{Fe} and u_{Si} , which Wever and Möller give as 0.134 ± 0.002 and 0.8445 ± 0.002 respectively. We have redetermined these constants with our specimen and obtained: $a = 4.4790_5$, $u_{\text{Fe}} = 0.146 \pm 0.002$, and $u_{\text{Si}} = 0.848 \pm 0.002$.

The structure appears to be a distortion of the NaCl type and bears no obvious relation to the α structure.

Formation of η .

The formation and dissociation of the η phase have been studied in detail by Lipson and Weill,¹⁶ who, on the basis of free-energy considerations, have put forward an explanation of why the η phase tends to appear before ϵ even outside the limits of its existence in the equilibrium diagram. In two-phase alloys near the α phase boundary the stability of η is most marked; in commercial alloys it behaves as the stable phase and ϵ is rarely detected. This may be due to the presence of carbon, but we have evidence that another factor is playing some part also.

The usual theories of equilibrium involve the assumption that the free energy of an alloy is the sum of the free energies of the phases of which it is composed. This neglects any possible energy in the surface of separation and, since the rules of equilibrium are usually well obeyed by alloy systems, it seems that this surface energy is small. But in systems such as iron-silicon, in which the difference of free energy due to change of phase of η to ϵ is very small (manifested by the extremely long times required to attain final equilibrium), it is possible that the surface energy may be an important factor in deciding which phase shall be the first to precipitate.

That structure will precipitate which has a lower surface energy than the other.

The possibility of the lower surface energy is due to a simple relation that exists between the η and α structures. In Fig. 6 are shown (a) the

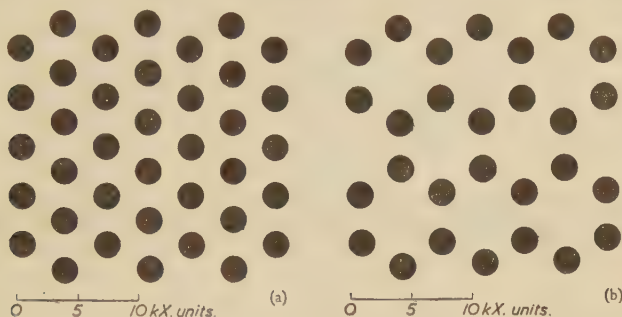


FIG. 6.—Arrangement of Iron Atoms (a) in the (111) planes of the α structure; (b) in the (0001) planes of the η structure at $z = 0$.

arrangement of atoms in the (111) planes of the α structure and (b) the arrangement in the (0001) planes of η at $z = 0$. It will be seen that these two arrangements have an obvious similarity both in pattern and in scale; it is therefore possible for the η structure to precipitate on the α structure without any abrupt change in atomic arrangement and so presumably with a relatively small surface energy. The ϵ structure has no such obvious relation to the α structure.

In support of this theory, we have noted that on photographs of coarsely crystalline two-phase alloys of $\alpha + \eta$, each of the 110 spots of the

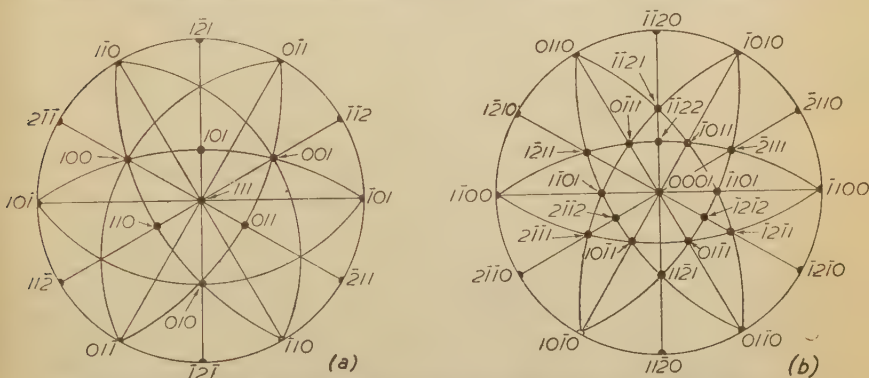


FIG. 7.—Stereographic Projection of (a) the α structure about the [111] axis; (b) the η structure about the [001] axis.

α phase was accompanied by a $11\bar{2}2$ spot of the η phase, at a slightly greater Bragg angle, and each of the 020 spots was accompanied in the same way by a $2\bar{2}42$ spot. The stereographic projections of the two phases (Fig. 7) show that the planes (010) and (110) of the cubic structure are parallel, respectively, to the $(11\bar{2}1)$ and $(2\bar{1}\bar{1}2)$ planes of the hexagonal structure if the [111] axis of α is parallel to the [001] axis of η and the

$[\bar{1}01]$ axis of α is parallel to the $[\bar{1}10]$ axis of η . The $22\bar{4}2$ reflection is the second order from the plane $(11\bar{2}1)$ and the $(2\bar{1}\bar{1}2)$ plane is, of course, one of the form $\{11\bar{2}2\}$.

The effect is very similar to that described by Preston,²⁰ who observed that the CuAl_2 phase precipitated in a matrix of aluminium has initially a structure of the CaF_2 type in preference to the more stable θ structure; the CaF_2 lattice has a close relationship in the aluminium lattice, whereas the lattice of the θ structure has not. It is hoped to carry out further experiments on the iron-silicon alloy in order to test the theory, but at present we have not succeeded in obtaining the single crystals required for a complete solution of the problem.

Formation of α'' .

The reaction which results in the formation of α'' is not clearly shown in Fig. 1, because the reaction point coincides almost exactly with the

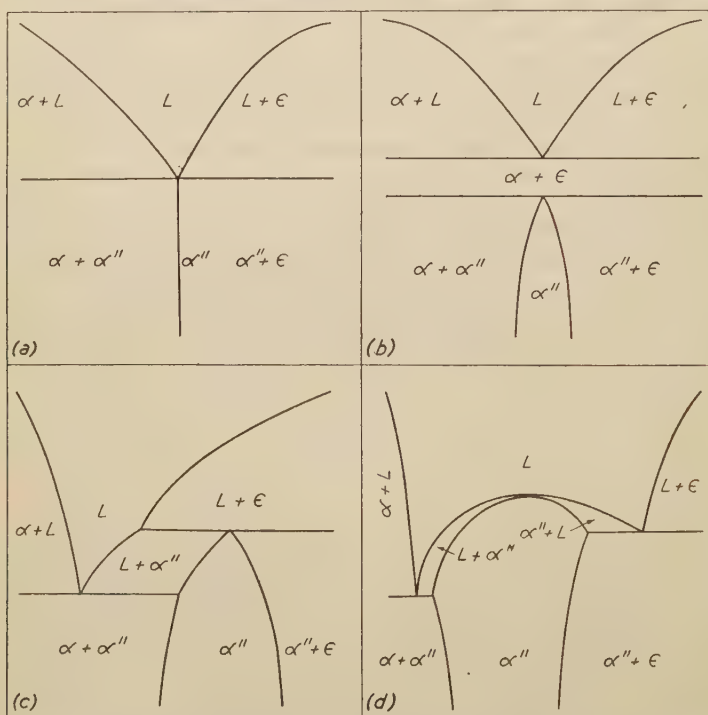


FIG. 8.—Formation of α'' (a) as represented in Fig. 1; (b) by a Peritectic Reaction at a temperature slightly lower than the eutectic temperature; (c) by a Peritectic Reaction at a temperature slightly greater than the eutectic temperature; (d) by a Polymorphic Reaction.

eutectic point, the compositions of both being near to 20% silicon. Such apparent exceptions to the phase rule appear quite frequently in published equilibrium diagrams, and are usually attributed to chance coincidences. This one, however, cannot be dismissed so easily, for it involves the simultaneous occurrence of two coincidences—the equality of the eutectic and reaction temperatures, and the equality of the compositions of the

eutectic and α'' . Since such an occurrence is extremely improbable, it is necessary to see whether the two coincidences are in fact unconnected, and the following reasoning suggests that they might not be.

There are three different forms that the relevant part of the equilibrium diagram might take, and of which that shown in Figs. 1 and 8(a) is a limiting case. The first is that α'' is formed by a peritectic reaction at a temperature slightly lower than the eutectic temperature, as shown in Fig. 8(b). If this is so, there would seem to be no reason why an approximate equality of the compositions of α'' and of the eutectic should result in approximate equality of the two temperatures, since the diagram could be drawn equally simply with the α'' phase field at any composition.

The other two possibilities are best discussed from the point of view of free energy.²¹ The condition for stability of a phase is that its free energy shall be less than the values that lie on the common tangent to neighbouring free-energy curves. Thus, if A , A'' , and E are the free-energy curves of α , α'' , and ϵ , α'' is stable in the case illustrated in Fig. 9(a). We

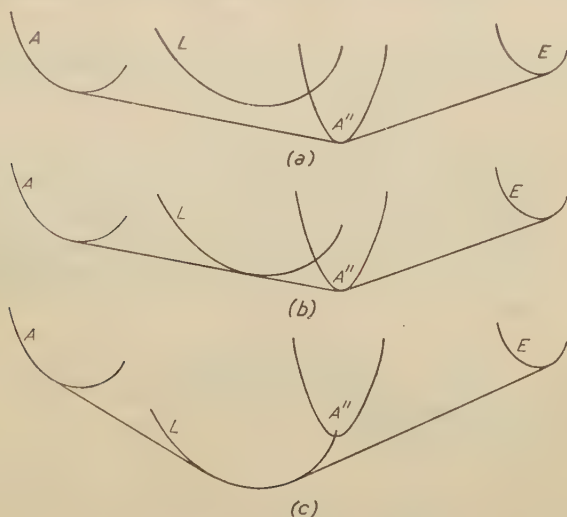


FIG. 9.—Hypothetical Free-Energy Curves for the different phases in the formation of α'' as shown in Fig. 8(c).

can now imagine a free-energy curve L for the liquid state, which becomes lower as the temperature rises. (The relative dispositions and shapes of the other curves may, of course, also change with temperature, but it is probable that the curve for the liquid state will change more quickly than those for the solid phases.) Suppose that the minimum of the curve L is near to that of the curve A'' . When L touches the common tangent to A and A'' (Fig. 9(b)) the liquid phase becomes stable, and so these conditions represent the formation of a eutectic. A further slight raising of the temperature and consequent lowering of the curve L will then cause the curve A'' to lie above the common tangent to L and E (Fig. 9(c)) and so α'' will disappear. The reaction resulting in the disappearance of α'' is a peritectic, and the resulting phase diagram is of the form shown in Fig. 8(c). It will thus be seen that the closeness of the eutectic and peritectic temperatures is a direct result of the closeness of the eutectic and peritectic compositions.

The reaction resulting in the formation of α'' can also assume another

form. If the curve L cuts both the common tangents to A'' before it comes below A'' , as shown in Fig. 10, two eutectics will be formed and α'' will be



FIG. 10.—Hypothetical Free-Energy Curves for the formation of α'' by a polymorphic reaction as shown in Fig. 8(d).

produced by a polymorphic reaction. This is illustrated in Fig. 8(d). Although this diagram seems different in nature from the previous one, it can be seen that according to free-energy principles there is essentially little difference. The limiting forms of both, with the detail condensed to approximate to a point, will give the features in the main equilibrium diagram (Figs. 1 and 8(a)).

In either of these latter reactions the coincidence in temperature follows from the coincidence in composition, whereas, in the first, two separate coincidences are required.

ACKNOWLEDGMENTS.

We wish to thank Professor Sir Lawrence Bragg and Dr. J. E. Hurst for their interest in this work and for their encouragement, and Mr. H. A. Sloman of the Metallurgy Division, National Physical Laboratory, and Mr. E. W. Colbeck, of I.C.I. Alkali Division, for preparing and analysing alloys for us. We also wish to acknowledge the kind interest of the Chief Scientific Officer, Ministry of Supply, by whose permission this paper has been published.

REFERENCES.

1. G. PHRAGMÉN: *Journal of The Iron and Steel Institute*, 1926, vol. 114, p. 394.
2. N. AGEW and G. SACHS: *Zeitschrift für Physik*, 1930, vol. 63, p. 293.
3. B. STOUGHTON and E. S. GREINER: "Metals Handbook," p. 396. Cleveland, 1939: American Society for Metals.
4. SUB-COMMITTEE OF THE MINISTRY OF SUPPLY: *Journal of the Society of Chemical Industry*, 1944, vol. 63, No. 2, p. 63.
5. J. L. HAUGHTON and M. L. BECKER: *Journal of The Iron and Steel Institute*, 1930, vol. 121, p. 315.
6. A. J. BRADLEY and A. H. JAY: *Proceedings of the Royal Society*, 1932, [A], vol. 136, p. 210.
7. CHU-PHAY YAP: *Journal of Physical Chemistry*, 1933, vol. 37, p. 935.
8. A. OSAWA and T. MURATA: *Nippon Kinzoku Gakkai-Si*, 1940, vol. 4, p. 228.
9. E. R. JETTE and E. S. GREINER: *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1933, vol. 105, p. 259.
10. E. S. GREINER and E. R. JETTE: *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1937, vol. 125, p. 473.
11. W. HUME-ROTHERY and G. V. RAYNOR: *Journal of Scientific Instruments*, 1941, vol. 18, p. 74.
12. H. LIPSON and L. E. ROGERS: *Philosophical Magazine*, 1944, [vii], vol. 35, p. 544.
13. W. HUME-ROTHERY and G. V. RAYNOR: *Proceedings of the Royal Society*, 1940, [A], vol. 177, p. 27.
14. A. J. C. WILSON: *Proceedings of the Physical Society*, 1941, vol. 53, p. 235.
15. H. LIPSON and A. R. WEILL: *Transactions of the Faraday Society*, 1943, vol. 39, p. 13.
16. A. R. WEILL: *Nature*, 1943, vol. 152, p. 413.
17. K. ÅMAR, B. BORÉN, and A. WESTGREN: *Svensk Kemisk Tidskrift*, 1936, vol. 48, p. 274.
18. B. BORÉN: *Arkiv för Kemi, Mineralogi och Geologi*, 1933, vol. 11, No. 10.
19. F. WEYER and H. MÖLLER: *Zeitschrift für Kristallographie*, 1930, vol. 75, p. 362.
20. G. D. PRESTON: *Philosophical Magazine*, 1938, [vii], vol. 26, p. 855.
21. H. LIPSON and A. J. C. WILSON: *Journal of The Iron and Steel Institute*, 1940, vol. 142, p. 107.

CORRESPONDENCE.

Dr. E. S. GREINER (Short Hills, N.J., U.S.A.) wrote: The authors are to be complimented on their interesting research on the constitution of iron-silicon alloys. The information obtained in this investigation will help to clarify the phase relations in this system.

The conclusion that the composition of the η phase seems to correspond to 23-25% of silicon, and should be described by the formula Fe_5Si_3 (23.16% of silicon), is in agreement with the results of Professor Jette and myself.* We observed that the η phase contains less silicon than the theoretical amount in the formula Fe_3Si_2 (25.09% of silicon). Our results showed that an iron-silicon alloy containing 24.75% of silicon quenched from 1020° C., and an alloy containing 25.06% of silicon quenched from 841°, 857° or 988° C. contain the η and ϵ (FeSi) phases.

Dr. K. M. GUGGENHEIMER, Mr. H. HEITLER (Bristol University) and Dr. K. HOSELITZ (Permanent Magnet Association, Sheffield) wrote: We have read the paper with great interest, since we have been engaged in a systematic magnetic study of iron-silicon alloys for a number of years. In the main, we agree with the results of the authors and have also found the four phases α , α'' , η , and ϵ . The first three phases, which are magnetic, are clearly distinguishable by their widely different magnetic properties. Quantitatively, however, our results differ in some respects from those of the authors. We should therefore like to ask what heat-treatment has been applied to the specimens listed in Tables I. and IV., and to the specimens of Figs. 2 and 3, because we found that both temperature and time of heat-treatment are very important.

AUTHORS' REPLY.

The AUTHORS wrote in reply: We thank Dr. Greiner for his encouraging remarks and are glad that he finds our estimation of the composition of the η phase to be in accordance with his and Professor Jette's results. Agreement on this point by two quite independent investigations is extremely valuable.

We shall be interested to see the results of Dr. Guggenheimer, Mr. Heitler and Dr. Hoselitz; we do not expect that finality has yet been reached in the system, and comparison of their results and ours may help to clear up some of the outstanding problems. We agree that both time and temperature of heat-treatment are important in producing equilibrium; this was shown in the results quoted in the paper by Lipson and Weill,† and these results were taken into consideration in deciding the heat-treatments necessary for the present investigation.

* *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1937, vol. 125, p. 473.

† *Transactions of the Faraday Society*, 1943, vol. 39, p. 13.

Details of the final heat-treatments for the alloys in which Dr. Guggenheimer, Mr. Heitler and Dr. Hoselitz are interested are as follows :

Table I.

Silicon, %.	Time, hr.	Temp., ° C.	
15.70	2	1060	} quenched in water.
	$1\frac{1}{2}$	960	
	16	1050	
16.65	2	1060	
	$1\frac{1}{2}$	960	
16.98	2	1060	
	16	1050	
18.00	16	1050	
	2	1060	
18.25	13	1040	
18.45	2	1060	

Most of the alloys were given more than one heat-treatment, but there were no significant changes in the lattice parameters.

Table IV.

Unfortunately, precise records of the heat-treatments are not now available. For lower temperatures up to 8 weeks' annealing was given before quenching, for the high temperatures about 3 days.

Fig. 2.

(c) 4 weeks at 715° C.	} quenched in water.
(d) 2 days at 950° C.	
(e) 16 hr. at 980° C.	
(f) 3 days at 940° C.	
(g) 20 hr. at 1100° C.	

Fig. 3.

$4\frac{1}{2}$ days at 1140° C., quenched in water.

A MICRO-SPECTROGRAPHIC METHOD FOR THE QUANTITATIVE ANALYSIS OF STEEL SEGREGATES.*

By J. CONVEY, M.Sc., Ph.D., F.Inst.P., AND J. H. OLDFIELD (THE BRAGG LABORATORY, NAVAL ORDNANCE INSPECTION DEPARTMENT, SHEFFIELD).

(Figs. 22 to 30 = Plates XLVI. to XLVIII.)

Paper No. 30/1945 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Inclusions Sub-Committee).

SYNOPSIS.

Steel-segregate analysis by the spot-spark method (*Journal of The Iron and Steel Institute*, 1941, No. II., p. 183 P) gave higher average values for all elements on the segregates than those on the normal metal. The elements manganese, molybdenum and vanadium showed the greater percentage increase. Careful examination of the segregate analyses revealed variations in element content within a single segregate. An attempt was made to determine the graduation in composition across a segregate by a careful linear location of the actual points tested. Although the results were good it was recognised that a technique was required whereby a continuous record of the variation in content across a segregate could be determined. A method was developed whereby the sample could be guided under a stationary upper electrode, while the photographic plate on which the spectrogram is recorded moved downwards across the camera aperture of the spectrograph. Spectrograms were obtained on which the spectral lines varied in density over their length according to local changes in the composition of the specimen along the path of the spark. By means of Meccano parts a system of transmission was designed and built. The speeds of transmission of the sample and the photographic plate were adjusted to give spectrograms of a density similar to that obtained by the spot-spark method.

Tests were made on several well-worked Ni-Cr-Mo steel bars of small section, and the results corroborated the content homogeneity of the bars. Spark traverses of the order of 7 mm. in length were made across various segregates in different types of steel and the results calibrated against standard steels. Such exposures produced spectrograms whereon the spectral lines were 5.4 cm. long. The clean definition and uniformity of the spectral lines throughout their lengths is a good proof of the continuity and smooth motion of the mechanical functioning of the traverse system. The effect of sparking on the steel samples is a crater very uniform in width (0.4 mm.) and depth (0.02 mm.) throughout its length (7 mm. approx.).

To obtain a quantitative analysis of the steels for carbon a higher steady-state potential of the spark gap was required. This was produced by blowing a small blast of dried air across the spark gap (pressure, $\frac{1}{2}$ in. of water). The method was standardised and tested. Analyses of segregates were identical with those obtained with the spot-spark and traverse-spark techniques without air blast. Variations in the macrostructures of segregates were found to agree with the content curves obtained *via* a traverse on the sample. Carbon content showed a slight decrease across the segregate in Ni-Cr-Mo alloy steels.

Introduction.

THE progress of spectrochemical analysis of metals and alloys is exemplified by the numerous publications on the subject during the past three or four

* Received October 14, 1944. This paper is published by authority of the Committee on the Heterogeneity of Steel Ingots. The views expressed in it are the authors' and are not necessarily endorsed by the Committee as a body.

years. A valuable contribution is the book by Twyman,⁽¹⁾ which is a very up-to-date and comprehensive survey of the complete subject. Reference may also be made to the publications of the Massachusetts Institute of Technology,⁽²⁾ Kaiser,⁽³⁾ Gerlach and Schweitzer,⁽⁴⁾ Brode,⁽⁵⁾ Smith,⁽⁶⁾ Scribner,⁽⁷⁾ and Churchill and Churchill.⁽⁸⁾ These and similar publications describe the principles of modern spectrochemical analysis and discuss the problems affecting the accuracy and consistency of the results. One of the most important variables met with in the analysis of metals and alloys is associated with the heterogeneity of the material under examination. This heterogeneity is especially evident in steels as segregates.

For routine spectrochemical analysis of steel, Barker⁽⁹⁾ minimised the effect of heterogeneity of composition on the results by superimposing six exposures to give one spectrogram, each exposure being made for a different position of the sample. This work eventually led to the application of spectrographic methods to the analysis of segregates in steel.⁽¹⁰⁾ A highly localised spark was used for the examination of minute areas of the sample. Thanheiser and Heyes⁽¹¹⁾ examined the inclusions in steel samples by sparking the inclusions through a hole from 0.01 to 0.02 mm. in dia. in a sheet of mica resting on the sample. Their results were essentially of a qualitative nature.

Scheibe and Martin⁽¹²⁾ developed a type of electrical discharge which affected an area 0.02 mm. in dia. on the metal surface. The spark, which was very small and weak, was substituted for the slit of the spectrograph. This micro-spark traversed the surface of a sample moving in conjunction with a moving spectrographic plate. This method produced a very weak but promising source for local microanalysis. Murray, Gettys and Ashley⁽¹³⁾ investigated the properties of Scheibe's source and made a few alterations. The source remained very weak, however, and this micro-spark also lacked sensitivity to small amounts of impurities in a metal.

The present investigation is a continuation of the authors' earlier work,⁽¹⁰⁾ and although similar in many respects to the technique of Scheibe, has developed independently. Segregation in steel is examined by traversing the sample with a highly localised condensed spark in conjunction with a moving spectrographic plate. This particular simple type of source is capable of a higher sensitivity to small differences of alloy content and is more intense than that of Scheibe's method. Although the amount of erosion of the specimen is greater, the results presented in this paper support the adopted technique for the analysis of the type of segregates met with in large steel forgings. Scheibe and Martin used inert atmospheres and worked at lowered pressures. Murray, Gettys and Ashley concluded that it was much simpler to operate the spark in air at atmospheric pressure, so avoiding the spectral banded structure (especially the nitrogen bands) which is produced with Scheibe's technique. By the present investigation it has been found that results are more satisfactory and an increase in sensitivity to small differences in composition is obtained when the spark operates under the influence of a current of air blown across the spark gap. The effect of air blasts on arcs and sparks has been studied^(14, 15) and been applied to spectroscopic work.

In addition to the quantitative analysis of the alloying constituents of steel, *viz.*, nickel, silicon, chromium, molybdenum, manganese and vanadium, by the internal standard method of Gerlach and Schweitzer,⁽⁴⁾ the authors have successfully applied the same method to the determination of carbon in steel. The problem of the spectrographic analysis of non-metallic elements in the presence of metallic elements is one of spark excitation, as the ionisation potential of the element which carries most of the current is decisive in controlling the relative intensity of the spectral lines of all elements present.^(16, 17) Investigations for the determination of

carbon in steel were made by Emery and Booth⁽¹⁸⁾ and later by Gatterer and Junkes.⁽¹⁹⁾ These authors point out the difficulties of excitation of the carbon and the limited choice of carbon spectral lines in a steel spectrogram; also, carbon in steel shows very little concentrational variation by ordinary spectrographic methods. Fortunately the present authors found that, with the aid of a current of air incident on the spark gap, the excitation is maintained at a potential which permits of the emission of the carbon spectral line C.III.2296.8Å. The results show a good variation in carbon-spectral-line density with respect to concentrational variation of the carbon content.

The following account presents in detail the progress of the investigation of the variation in element concentration across segregates in steel. Seven elements were studied, *viz.*, silicon, manganese, nickel, chromium, molybdenum, vanadium and carbon.

Localised Micro-Analysis by the Spot-Spark Method.

In the development of a spectrochemical method for the quantitative analysis of steel⁽⁹⁾ it was found necessary to superimpose six exposures, taken at different positions on the surface of the sample, in order to give a true representation of the average composition of the sample. The necessity for superimposed exposures was due to the degree of heterogeneity exhibited by the samples examined, particularly those taken from large masses of steel on which a relatively small amount of work had been done. Effects of segregation were examined by positioning the centres of the segregates immediately below the point of the upper graphite electrode and sparking; tests were also made in positions clear of the segregates. This method yielded, at least, a qualitative estimate of the composition of metallic segregates.

A modification of this technique was made by the authors,⁽¹⁰⁾ whereby the area of the segregate affected by the sparking was smaller (the diameter of the crater being reduced from 1.02 mm. (0.04 in.) to 0.31 mm. (0.012 in.)), and spectrograms were obtained from single exposures.

This resulted in a quantitative analysis of segregates. For convenience, the conditions provisionally adopted are given below :

Instrument used	Hilger E.1. quartz spectrograph.
Wave band	2200–3000 Å.
Width of slit	0.0015 cm. (0.006 in.).
Distance of electrode from slit	10 cm. (4 in.).
Width of spark gap	0.038 cm. (0.015 in.).
Voltage	15,000 (open circuit).
Added inductance	Nil
Upper electrode	Silver rod (7 mm. in dia.), nipple-pointed, height of nipple point, 1.50 mm. (0.05 in.), angle 36°, oxidised by pre-sparking for 15 sec.
Plate	Kodak Photocript B.10.
Exposure time	15 sec.

Plate Processing.

A one-solution developer of the following composition was used :

Metol	5.0 g.
Hydroquinone	11.0 g.
Sodium sulphite (anhydrous)	65.0 g.
Sodium carbonate (anhydrous)	45.0 g.
Potassium bromide	1.5 g.

Made up with water to 5000 c.c.

A system of pyrogalllic-acid traps containing a solution of 10% pyrogalllic acid in 10% sodium hydroxide was connected to the aspirator containing the developer. Details of this system are to be published separately.

The plates were immersed in 100 cc. of the developer and developed for

90 sec., at a temperature of 67° F., the solution being agitated by random hand-rocking.

The developed plates were fixed for three minutes in an acid fixing bath of the following composition :

Solution A :

Sodium thiosulphate	200 g.
Water	1000 cc.

Solution B :

Potash alum	15 g.
Sodium sulphite	15 g.
Glacial acetic acid	12 cc.
Water	150 cc.

Solutions A and B were made separately and then mixed together in the same container.

The plates were washed in running water for twenty minutes and, finally, in distilled water, and then dried in air at room temperature. The dark room was thermostatically controlled at 67° F.

To indicate segregation specimens were etched with Oberhoffer's reagent.

A Hilger non-recording micro-photometer was employed throughout.

In Table I. are recorded the spectral-line pairs used in the analyses.

TABLE I.—*Spectral-Line Pairs.*

Element.	Classification.	Wave-Length. Å.	Composition Range. %.
Silicon	Si.I.	2881.578	} 0.05-0.60
	Fe.I.	2874.172	
Manganese	Mn	2933.063	} 0.05-1.00
	Fe.I.	2936.905	
Nickel	Ni.II.	2416.138	} 0.05-1.50
	Fe.II.	2415.063	
	Ni.II.	2312.916	} 1.00-5.00
	Fe.II.	2312.034	
Chromium	Cr.II.	2677.159	} 0.05-1.60
	Fe.I.	2679.062	
Molybdenum	Mo.II.	2816.154	} 0.05-1.00
	Fe.II.	2813.613	
Vanadium	V.II.	2908.817	} 0.05-0.50
	Fe.I.	2912.158	

The classification and wave-lengths shown in Table I. are those given by Harrison.⁽²⁰⁾

It was shown in the earlier work⁽¹⁰⁾ that tests on small bars of nickel-chromium-molybdenum steel in which any segregates present were of negligible dimensions gave a reproducibility of a satisfactory order (*loc. cit.*, p. 192 P). Tests on specimens from large forgings of nickel-chromium-molybdenum and nickel-vanadium steels showing marked segregation gave higher values for all elements in the segregates, as compared with the respective values for the matrix of the steel (*loc. cit.*, pp. 188 P-191 P). Table II. presents a typical summary of these results.

A more detailed examination of the results showed variations in composition to occur within a single segregate. An attempt was made, therefore, to determine the graduation in composition across a segregate. This was done by a careful location of the actual points tested, so that their positions relative to each other lay in a straight line.

The results of analyses of segregates occurring in two steel samples, A and B, taken from large nickel-chromium-molybdenum steel forgings, are given in Tables III. and IV. The location of the areas tested on the respective samples A and B is shown in Figs. 22 and 23.

TABLE II.—Average Results of Tests on Nickel-Chromium-Molybdenum Steel A and a Nickel-Vanadium Steel.

	Si. %.	Mn. %.	Ni. %.	Cr. %.	Mo. %.	V. %.
<i>Ni-Cr-Mo Steel A.</i>						
Non-segregate	0.17	0.47	2.68	0.59	0.40	...
Greatest deviation from average :						
Above	+0.01	+0.03	+0.09	+0.06	+0.03	...
Below	-0.02	-0.02	-0.13	-0.04	-0.03	...
Segregate	0.20	0.55	2.92	0.68	0.62	...
Greatest deviation from average :						
Above	+0.01	+0.18	+0.15	+0.07	+0.26	...
Below	-0.01	-0.08	-0.16	-0.07	-0.11	...
<i>Ni-V Steel.</i>						
Non-segregate	0.25	0.68	2.54	0.14	0.12	0.09
Greatest deviation from average :						
Above	+0.04	+0.08	+0.09	+0.01	+0.07	+0.05
Below	-0.02	-0.06	-0.07	-0.01	-0.02	-0.03
Segregate	0.26	0.80	2.74	0.15	0.17	0.18
Greatest deviation from average :						
Above	+0.02	+0.05	+0.06	+0.02	+0.03	+0.03
Below	-0.02	-0.07	-0.07	-0.02	-0.04	-0.02

TABLE III.—Results of Tests on Nickel-Chromium-Molybdenum Steel A.

Test No.	Si. %.	Mn. %.	Ni. %.	Cr. %.	Mo. %.
1	0.19	0.43	2.51	0.66	0.61
2	0.18	0.42	2.37	0.68	0.63
3	0.21	0.61	2.70	0.72	0.80
4	0.21	0.55	2.63	0.76	0.80
5	0.19	0.41	2.55	0.67	0.67
6	0.19	0.45	2.51	0.71	0.63
7	0.19	0.54	2.56	0.66	0.60
8	0.21	0.75	2.72	0.79	0.90
9	0.19	0.43	2.73	0.72	0.76
10	0.19	0.45	2.70	0.73	0.82

TABLE IV.—Results of Tests on Nickel-Chromium-Molybdenum Steel B.

Test No.	Si. %.	Mn. %.	Ni. %.	Cr. %.	Mo. %.
1	0.17	0.53	2.56	0.68	0.53
2	0.20	0.70	2.82	0.78	0.85
3	0.20	0.65	2.55	0.76	0.69
4	0.20	0.63	2.40	0.74	0.64
5	0.17	0.52	2.42	0.70	0.53
6	0.17	0.52	2.32	0.67	0.51
7	0.20	0.62	2.53	0.72	0.63
8	0.22	0.57	2.54	0.76	0.83
9	0.24	0.68	2.83	0.82	0.90
10	0.18	0.51	2.42	0.70	0.63
11	0.24	0.70	2.65	0.78	0.79
12	0.22	0.61	2.54	0.76	0.66
13	0.18	0.80	2.71	0.81	0.90
14	0.22	0.72	2.82	0.81	0.83

In Fig. 1 are plotted the results given in Table III., viz., percentage composition with respect to the relative positions of the tests along the designated sections *AB* and *CD*, respectively (see Fig. 22).

The results given in Table IV. are plotted in Fig. 2; marked segregation of molybdenum, chromium and manganese occurs.

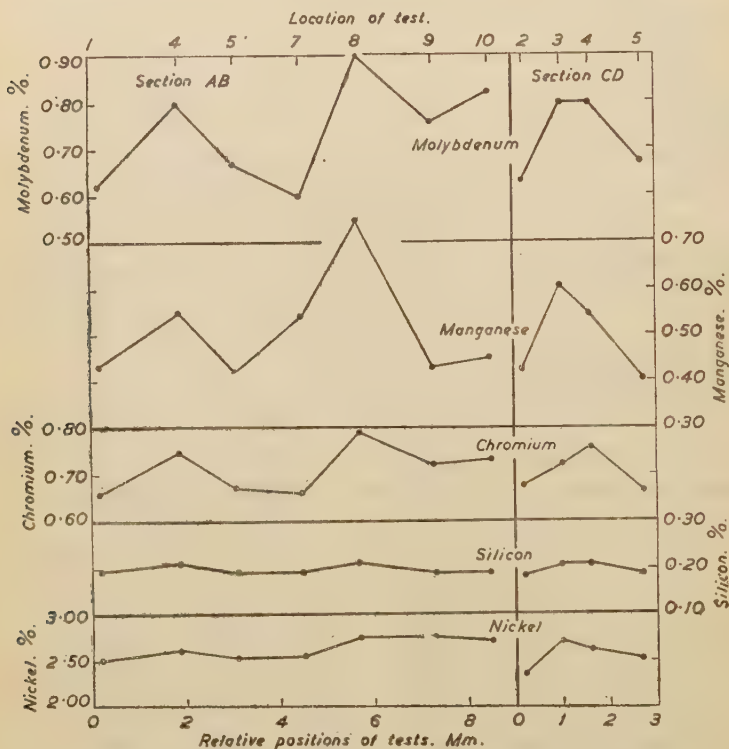


FIG. 1.—Analysis of Segregate in Sample A.

Development of the Traverse Spark Technique.

Owing to the stringent optical conditions required by the spot method, it proved to be a difficult task to control a specified location of the sparked areas when investigating the varying composition of a segregate. It was therefore necessary to develop a technique whereby a continuous analysis of the variation in composition across a segregate could be made. Such a method was considered possible if the sample could be guided under a stationary upper electrode, while the photographic plate on which the spectrum was being recorded moved downwards across the camera aperture of the spectrograph. Thus, a spectrogram would be obtained on which the spectral lines vary in density over their length according to local changes in the composition of the specimen along the path of the spark.

The requirement was that the spectrograms would be of the same order of density as those obtained with the spot-spark technique,⁽¹⁰⁾ i.e., 'with respect to a 3-mm. length of spectral line, produced by a stationary exposure of 15 sec. By means of Meccano parts a system of transmission

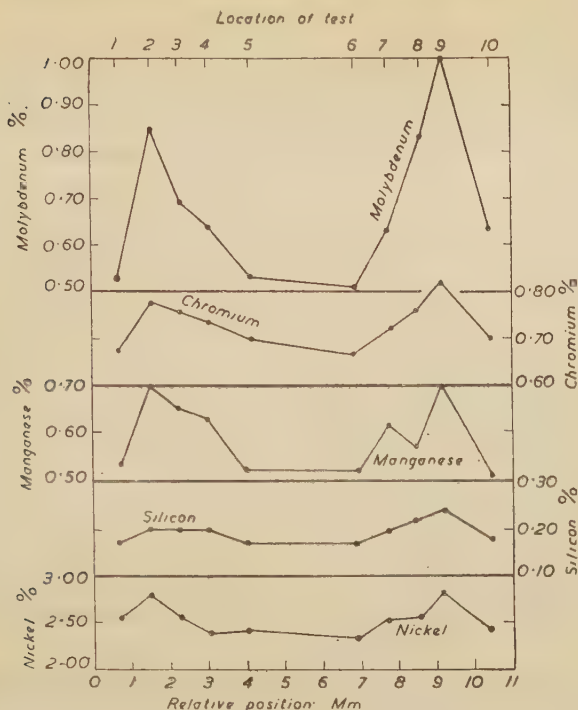


FIG. 2.—Analysis of Segregate in Sample B.

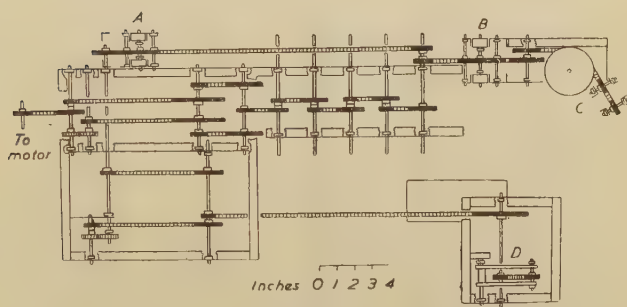


FIG. 3.—Diagram of Traversing Gear.

was designed and built as shown in Figs. 3 and 25. This system resulted in a synchronised movement of the sample and the photographic plate, and produced a spectrogram with lines of the required density.

The traversing gear was actuated by a $\frac{1}{10}$ -h.p. motor running direct from the main A.C. supply of 200 V. A system of chains and sprockets made it possible to vary the traversing rate as desired; the sprocket sizes were 14, 18, 28, 36 and 56 teeth. The two towers A and B (Fig. 3) were designed to take up the slack in the chain when the sprockets were moved

on to different axes. Tower *C* (Fig. 3) elevates the driving chain to the same height as the mechanism which moves the spectrographic plate. The jockey arm *D* takes up the slack in the chain which drives the traversing gear of the microscope stage supporting the sample under examination. This microscope stage can be adjusted to different heights to permit the investigation of samples of different thickness. The traversing gears were arranged to allow for the independent motion of either the spectrographic plate or the sample.

The first tests were made on a nickel-chromium-molybdenum steel bar of small section, in which the ingot structure had been well broken down and in which there was relatively little evidence of heterogeneity. This specimen is designated as sample *C*. The experimental conditions, except those demanded by the traversing, were as previously given for the spot-spark method. Two successive traverses of two minutes' duration were made, covering a total traversed length of specimen of approximately 5 mm. The spectrogram obtained consisted of well defined uniform spectral lines of length approximately 30 mm. The densities of the respective spectral-line pairs for each element were measured in 2 mm. steps on a Hilger non-recording microphotometer. As a trial, the relative percentage contents of the elements present were determined from standard curves obtained previously by the spot-spark technique. In consistency the results compared favourably with those obtained during the earlier work⁽¹⁰⁾ (*loc. cit.*, p. 192 P) from the spot-spark-test analysis on the same sample.

Using the same conditions as above, an exposure was then made by traversing across the segregate in the steel sample *A*. That is, two collinear successive two-minute traverses were made across the segregate at an angle of 45 degrees with its longitudinal axis. The results obtained are given in Table V. and illustrated in Fig. 4.

TABLE V.—*Results of Test on Nickel-Chromium-Molybdenum Steel A.*

Si. %.	Mn. %.	Ni. %.	Cr. %.	Mo. %.
0.12	0.34	2.43	0.63	0.41
0.11	0.34	2.54	0.57	0.41
...	0.35	2.65	0.58	0.43
0.11	0.34	2.72	0.56	0.42
0.12	0.34	2.65	0.55	0.40
0.10	0.35	2.65	0.57	0.36
0.09	0.34	2.60	0.56	0.40
0.10	0.34	2.65	0.60	0.43
0.09	0.37	2.78	0.62	0.47
0.10	0.38	2.83	0.62	0.50
0.12	0.41	3.02	0.62	0.56
0.13	0.39	3.02	0.61	0.56
0.10	0.43	2.83	0.72	0.59
0.10	0.44	2.95	0.68	0.62
0.10	0.43	2.88	0.68	0.60
0.11	0.39	2.80	0.65	0.56
0.10	0.41	2.72	0.62	0.52
0.10	0.37	2.62	0.62	0.48
0.09	0.35	2.71	0.63	0.47
0.09	0.35	2.71	0.62	0.44
0.10	0.37	2.70	0.61	0.47
0.12	0.38	2.75	0.60	0.48
0.11	0.39	2.72	0.62	0.48
0.11	0.35	2.72	0.62	0.47

Fig. 4 shows the percentage content of each element, as obtained from the measurement of the density of each 2 mm. of the respective spectral-line pairs, plotted against the corresponding traversed distance of the sample.

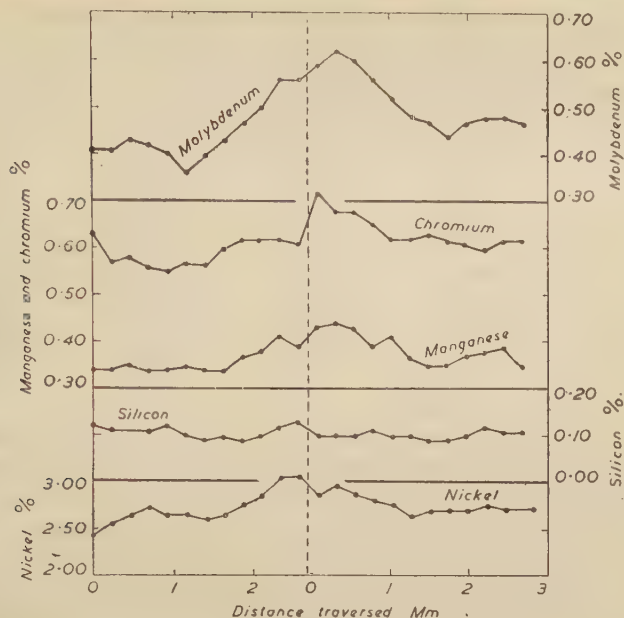


FIG. 4.—Analysis of Segregate in Sample A.

The dotted line in Fig. 4 represents the break in continuity of the traverse. In spite of this interruption in the exposure the apparent continuity of the results is very marked, a feature which was observed in later work. The difference in the percentage composition between the main segregate and non-segregated material compares quite favourably with that obtained by the spot-spark technique (Fig. 1), although no standardisation of the method had been made. For tests across fairly large segregates, however, it was necessary to increase the length of the traverse and so obtain an analysis of a segregate with one traverse and not with a series of exposures. This required traverses of the order of 7 mm. in length, and the question arose, how would the silver nipple electrode respond to such prolonged exposures? Tests were therefore made to determine the extent of erosion of the electrode nipple due to a prolonged period of sparking. A series of measurements of the length of the electrode nipple was taken before and after periods of sparking varying in magnitude from 5 sec. to 10 min. No serious diminution in the length of the electrode nipple was observed after an initial spark period of 15 sec. up to a continuous spark period of 8 min. During the first 15 sec. an average loss of 0.2 mm. was observed in the height of the electrode nipple. Table VI. presents a sample of the observations of electrode loss due to sparking periods of 15 sec. and 8 min.

In addition, specially prepared electrode-tips of 10% and 20% platinum-iridium alloys were tested for spark durability. The results were negative, as these electrodes exhibited selective sparking which resulted in an irregular-shaped and larger crater. In view of these results it was decided to continue all future work with the silver electrodes.

The steel sample *C* (a Ni-Cr-Mo bar of small section) was then traversed for 7 min. This exposure gave spectral lines of length 5.4 cm., as recorded on the spectrographic plate. The spectrogram is reproduced in Fig. 24, 1945—ii

TABLE VI.—Results of Tests on the Breakdown of the Nipple of a Silver Electrode after 15-sec. and 8-min. Sparking Periods.

Original Length of Electrode Nipple. Mm.	Length of Silver Nipple After 15 Sec. Pre-Sparking. Mm.	Length of Silver Nipple After 8 Min. Sparking. Mm.	Loss After 15 Sec. Pre-Sparking. Mm.	Loss After 8 Min. Sparking. Mm.
1.55	1.35	1.20	0.20	0.15
1.60	1.40	1.30	0.20	0.10
1.70	1.50	1.40	0.20	0.10
1.60	1.40	1.25	0.20	0.15
1.50	1.30	1.20	0.30	0.10
1.60	1.50	1.30	0.10	0.20
1.60	1.40	1.30	0.20	0.10
1.60	1.40	1.30	0.20	0.10
1.60	1.40	1.30	0.20	0.10
1.50	1.30	1.15	0.20	0.15
1.60	1.35	1.25	0.25	0.10
1.55	1.35	1.30	0.20	0.05
1.60	1.40	1.30	0.20	0.10

which shows the clarity and uniformity of the spectral lines throughout their length. Such a spectrogram is a good indication of the continuity and smooth motion of the mechanical functioning of the assembled apparatus illustrated in Figs. 3 and 25.

The effect of the traverse-sparking of the steel sample produces a crater (Fig. 26) which is very uniform in width and depth throughout its length. The width and depth are 0.4 mm. (0.015 in.) and 0.02 mm. (0.0008 in.) respectively. The results of the traverse of steel sample C are plotted in Fig. 5, and these confirm the observations established by previous spot-spark tests⁽¹⁰⁾ (*loc. cit.*, p. 192 P).

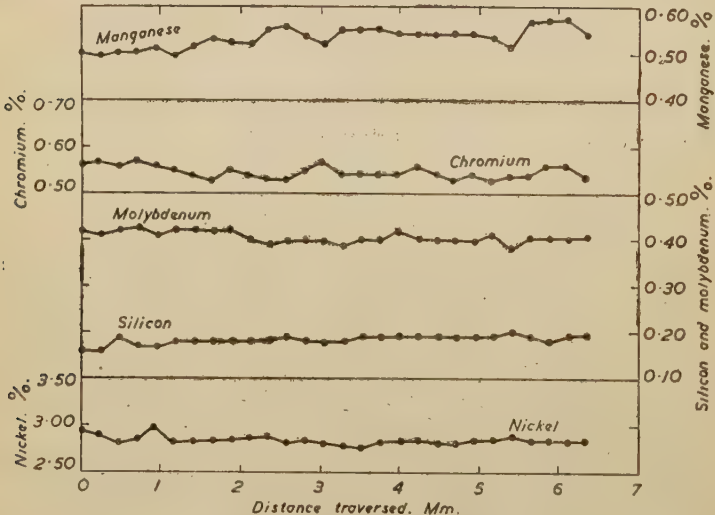


FIG. 5.—Analysis of Sample C.

Tests to obtain a measure of the localisation of the emission were made by spark-traversing the inset steel bar used in the earlier work (*loc. cit.*, pp. 186 P-187 P), *i.e.*, Ni-Cr-Mo alloy-steel bar set in a block of mild steel

which contained only traces of the alloying elements nickel, chromium, molybdenum, &c. The spark traverses were made in opposite directions, namely, from the mild-steel block to the inset alloy steel and then in the reverse direction. A sample of the results is given in Fig. 6.

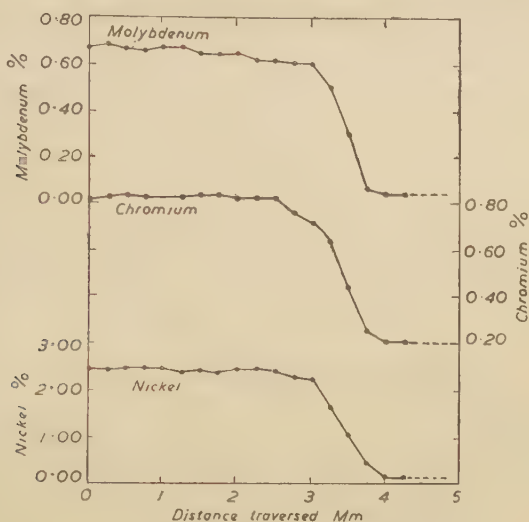


FIG. 6.—Analysis of Inset Steel Bar.

These observations established that the emission from the secondary discharge, which forms a halo⁽¹⁰⁾ around the main crater owing to the primary discharge, is negligible, as Fig. 6 exhibits a sudden change in content when the spark traverse crosses the junction of the two steels.

The segregate in steel sample *A* was then spark-traversed for 7 min. and the results obtained were similar to those plotted in Fig. 4. It was reasonable, therefore, to assume that the method of traversing was applicable to the problem under consideration.

Standardisation and Application of the Traverse-Spark Method.

With the addition of the rate of traverse of the sample, 0.9 mm. per min., and the rate of fall of the photographic plate, 7.7 mm. per min., to the experimental conditions given earlier for the spot-spark method, the method of spark-traverse analysis was standardised as follows:

Exposures were obtained from eight chemically standardised steels under the conditions stated above. From the results standard calibration curves were prepared relating the log ratios of the respective spectral-line densities to the percentage contents of elements present. Each point on the standard curves represents the average of approximately thirty density readings obtained for the respective elements in the eight standard steels. The curves are similar to those obtained in the earlier work⁽¹⁰⁾ (*loc. cit.*, pp. 186 P–188 P).

The segregates in the steel samples *A* and *B* were traversed, and the resulting spectrograms calibrated according to the above-mentioned standard curves.

The results are similar to those given above in Figs. 1, 2 and 4, respectively.

Another steel sample, *D*, cut from a forging of similar composition to

sample *A* and containing segregation of a similar nature was also examined. Figure 27 shows the macro-structure and the segregate of sample *D* before sparking. Several traverses, each of approximately seven minutes duration, were made across the longitudinal section of the segregate in the positions shown in Fig. 28. The observations for four of the traverses, namely, 1 to 4 inclusive, as indicated in Fig. 28, are presented graphically in Figs. 7 to 10, respectively.

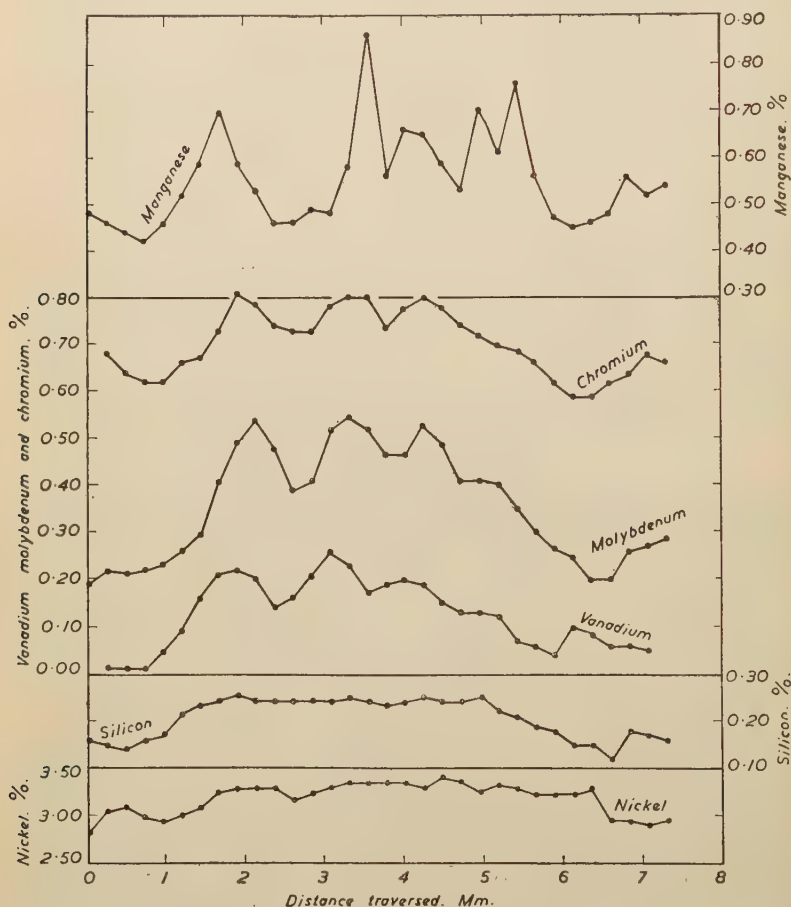


FIG. 7.—Analysis of Sample *D*, traverse 1.

As usual, high average content for all elements was obtained on the segregates, with the greater percentage-content increases for manganese, molybdenum and vanadium. Furthermore, marked variations in composition were shown to exist within the segregates. This feature is especially evident in Fig. 7, which corresponds to the variable macro-structure shown in Fig. 27. Traverse 4 (Fig. 10) was made in a direction opposite to traverses 1, 2 and 3. From the macro-prints (Figs. 27 and 28)

one would expect comparatively similar results for each of the traverses 2, 3 and 4. This feature is exhibited by Figs. 8, 9 and 10.

In accordance with the adopted technique the steel samples were polished and then etched with Oberhoffer's reagent in order to reveal the macrostructures and the segregates. It was decided, therefore, to make a series of exposures on the steel sample *C* in the polished-unetched and polished-etched conditions, respectively, in order to observe the effect, if any, of the etching of the samples. The results indicated only a very slight

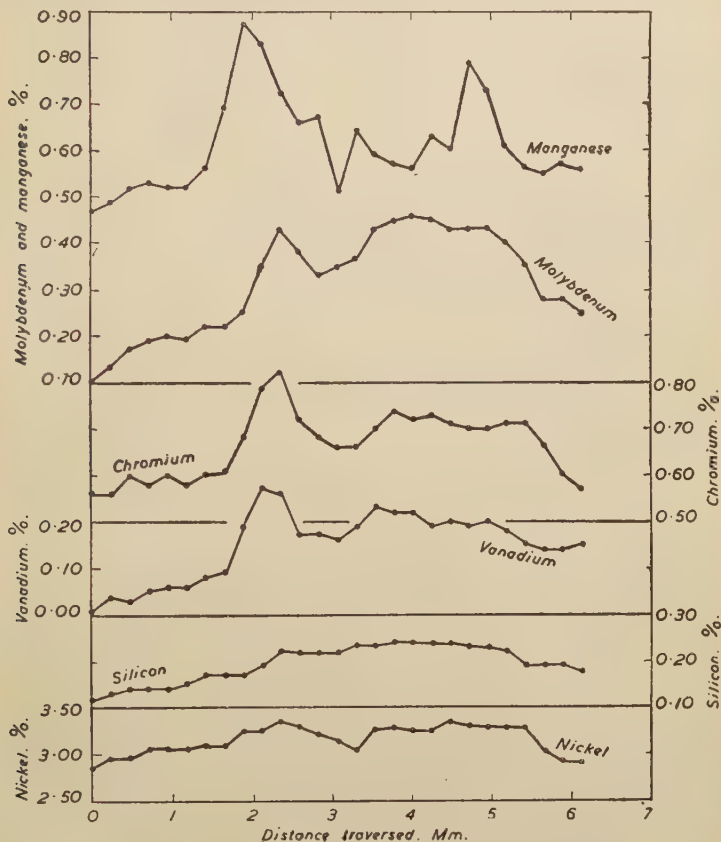


FIG. 8.—Analysis of Sample D, traverse 2.

positive shift in content for each of the elements measured with respect to the unetched samples. This shift disappears when the observations for the unetched condition are calibrated against unetched standards. The results under both conditions were identical.

Quantitative Analysis of Carbon.

All spectrograms obtained during the course of the previous investigation were carefully examined for the carbon content of each of the steel samples. The results obtained were very unsatisfactory. Unfortunately

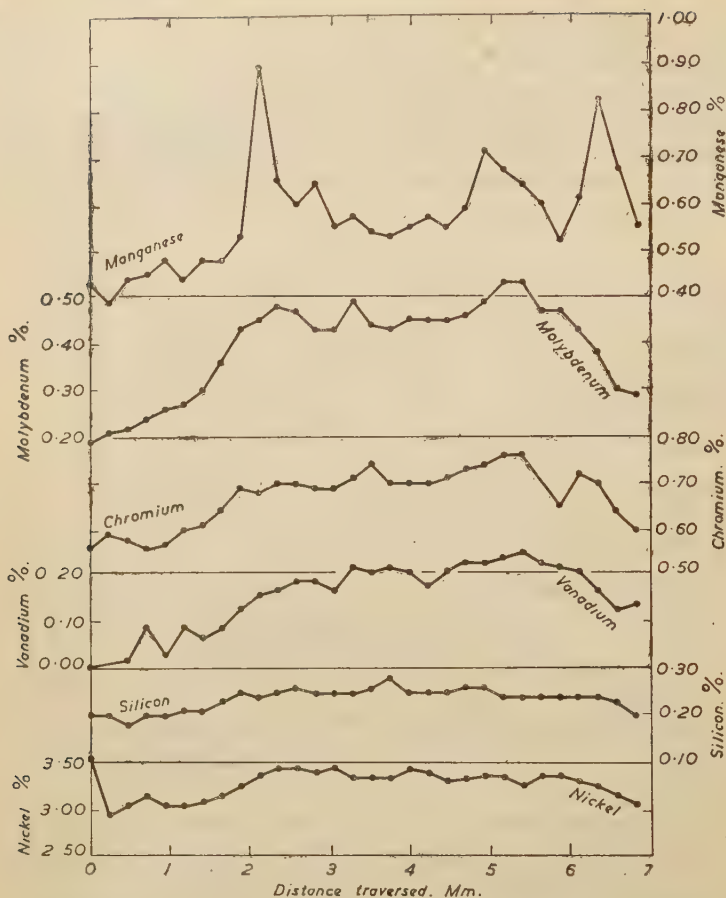


FIG. 9.—Analysis of Sample D, traverse 3.

the only available carbon spectral line in the adopted spectral region 2200–3000 Å is the doubly ionised carbon line 2296.8 Å. Under the exposure conditions previously described this carbon line is very weak, and also suffers a rapid decrease in intensity as the traverse progresses, *i.e.*, the carbon emission rapidly diminishes. This difficulty is due to the spark gap becoming saturated with the ions of the metallic elements, and these ions will do most of the work of current transfer in the spark at a lower potential than that required to excite the non-metal carbon, particularly for the emission of the C.III.2296.8 Å wave-length.

For uniform carbon emission, therefore, two problems required to be solved: (1) that of increasing the effective steady-state potential of the spark gap so as to favour the emission of the C.III.2296.8 Å line, and (2) that of increasing the photometric density of the C.III.2296.8 Å line as recorded on the spectrographic plate.

Question (2) was answered by moving the source towards the spectrographic slit in 1-cm. (0.45-in.) steps. This resulted in an increase of the

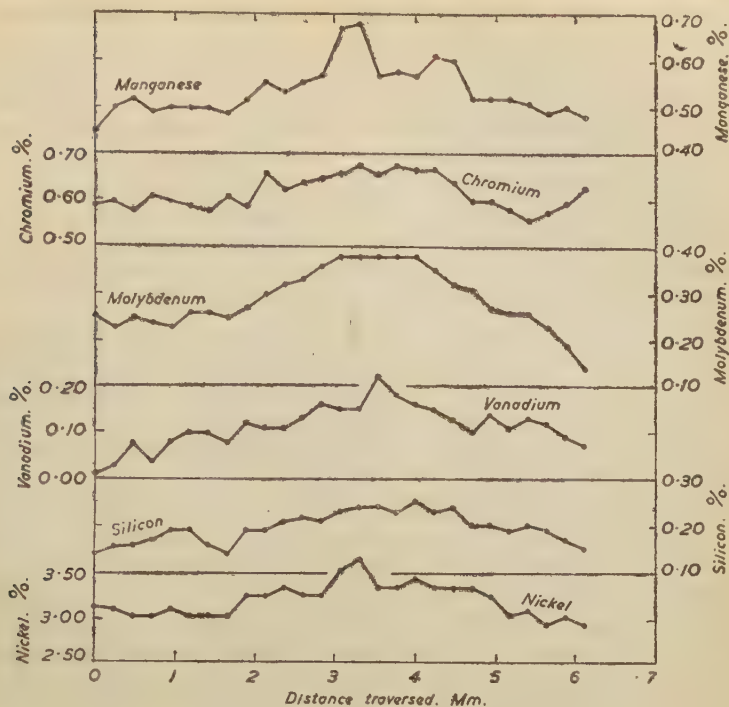


FIG. 10.—Analysis of Sample D, traverse 4.

recorded C.III.2296.8 Å line density. At a position 7 cm. from the slit the image of the source just filled the collimating lens of the spectrograph; this limiting position of the source relative to the slit was therefore adopted for future tests.

In addition to the above change, the rate of fall of the photographic plate was reduced to approximately $\frac{1}{4}$ of its previous speed, and a further increase in the carbon-line density was obtained.

To increase the steady-state potential of the spark gap several tests were made. The first test was the use of an auxiliary spark gap, varying in width from 2 to 6 mm., in series with the analysis spark. A general increase in the density of the spectrogram was observed, including the carbon line 2296.8 Å. The appearance of higher-order spark spectral lines indicated an increase in the potential across the spark gap. In spite of this success, however, the method had to be abandoned, as the silver-electrode tip underwent an appreciable erosion in all tests, and a marked increase in temperature of the test sample was observed.

A second series of tests was made using a rotary spark interrupter. The latter was driven by a motor which completed the circuit for only a short time every half-cycle of the A.C. mains by means of a subsidiary spark gap. This rotary spark gap was in series with the main spark and thus permitted only the first of each train of sparks to occur between the steel sample and the silver electrode. As in the previous experiment, an increased and more stable carbon emission was obtained, but there was an

extensive breakdown of the tip of the silver electrode. Other methods of attack were, therefore, sought.

As the traverse progresses, the temperature of the steel sample rises, thus increasing the quantity of metallic vapour present in the spark gap and lowering the degree of electrical excitation. Tests were made with a view to reducing the heat generated in the sample during sparking and so preventing a too abundant emission of metallic vapour. The tests were made on the homogeneous steel sample *C*; this was traversed at room temperature for seven minutes, then cooled in carbon-dioxide snow for two hours and then traversed again for another seven minutes; the procedure was then repeated. Although the pre-cooling of the sample resulted in a slight increase in the carbon emission, the carbon-line density was still observed to decrease as the traverse progressed. The ionic state of the spark gap, therefore, was not essentially a thermal effect.

This failure led to a more mechanical attack, namely, a sweep of the spark gap with a current of air to remove the excess ionised vapour. The requisite pressure of cold air was adequately maintained by a small hair-dryer and a ten-litre aspirator as a reservoir. The air was dried by passing through calcium-chloride and cotton-wool traps, and the pressure measured by means of a manometer gauge. The air blast was directed on to the spark by means of glass tubing of 4 mm. internal diameter.

A test was made on steel sample *C* during a traverse of seven minutes, using a current of air at a pressure of 2 in. of water incident on the spark gap. A marked increase in the general density of the spectrogram was observed. In addition, the density of the carbon line 2296.8 \AA was enhanced and showed no sign of any decrease of density as the traverse progressed. A comprehensive comparison of the spectral lines recorded during the traverse of the steel sample *C* with and without an air current, respectively, was made for three-minute traverses, and the spectrograms recorded on the same plate. The increase in overall density of the spectrogram with air blast as compared with that without air blast was very marked. Close examination revealed the emission of a few extra spectral lines, probably of a higher order of ionisation.

A series of exposures for various incident air pressures was then made. Only a very small relative increase in the spectral-line density corresponding to the variation of the air pressures through $\frac{1}{2}$, 1, 2, 4, 6, 8 and 10 in. of water was found. At the higher pressures the spark tended to be blown from its course, and thus the spark crater area was not uniform in width. The air current of lowest pressure ($\frac{1}{2}$ in. of water) was therefore adopted. The air current was also directed at different angles to the line of traverse. Furthermore, tests were made with two and three simultaneous air currents, one at right-angles to, the others in the direction of and opposed to, the line of traverse. It was found inadvisable, however, to use more than one current of air; this should be directed at right-angles to the line of traverse at an angle of incidence of approximately 45 degrees from the direction of the slit.

Furthermore, during the above tests it was found advisable to use the initial rate of fall of the photographic plate, namely, 7.7 mm. per min. Under these new conditions the width of the crater was observed to be 0.64 mm. (0.025 in.), which is 0.24 mm. (0.010 in.) greater than the crater obtained without the air blast.

This small incident current of air appears to fulfil the purpose of sweeping the excess metallic ions from the spark gap, and the potential between the silver electrode and the sample is maintained at a higher and more uniform level, as shown by the results quoted in the later pages of this paper. This increase in the steady-state potential between the electrodes favours the spectral emission of carbon, hence the ability to determine the carbon

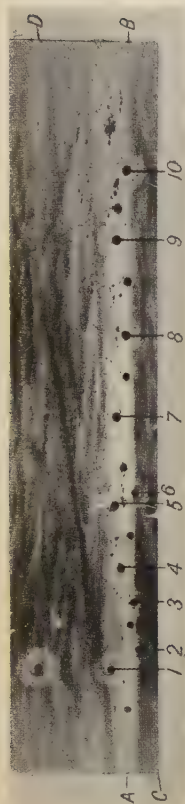


FIG. 22.—Displacement of Sparked Areas in Sample A. $\times 24$.

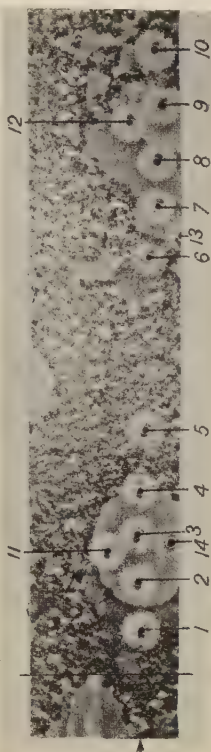


FIG. 23.—Displacement of Sparked Areas in Sample B. $\times 24$.

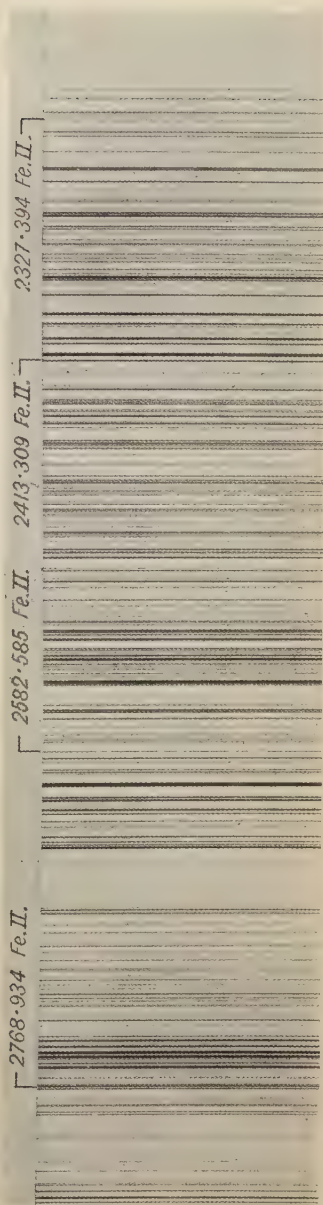


FIG. 24.—Spectrogram Obtained with Moving Plate. $\times 0.8$.

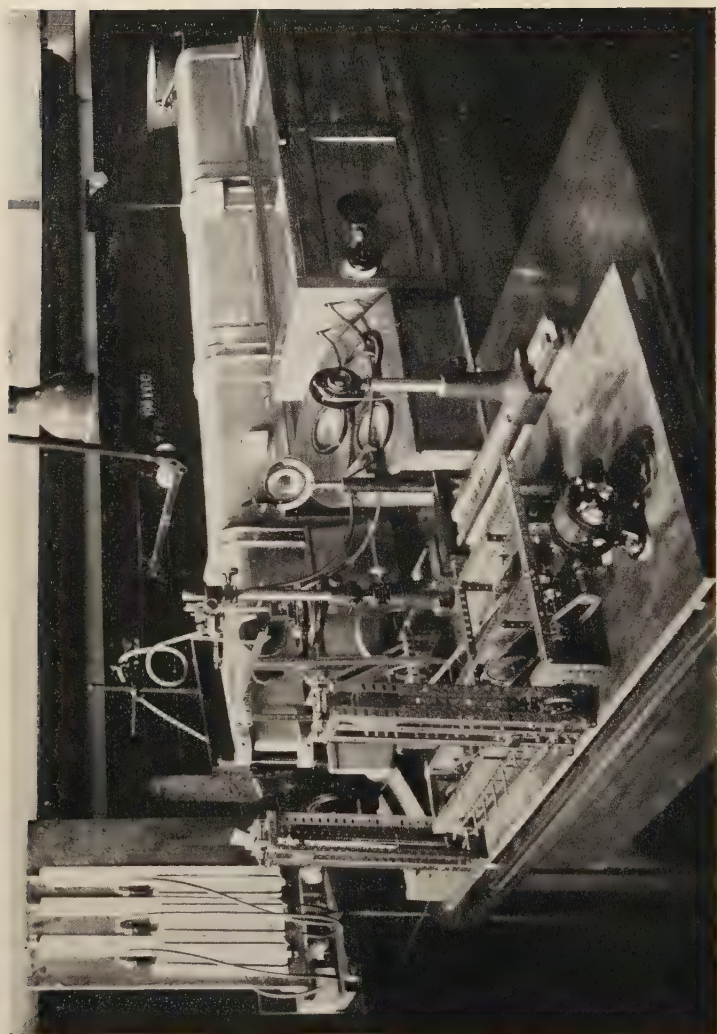
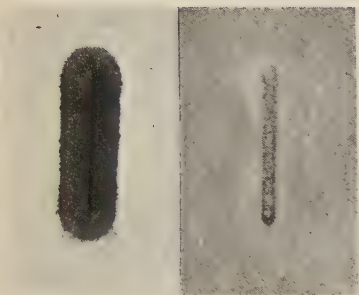


FIG. 25.—Traversing Gear.



(a) With Corona. (b) Without Corona.
FIG. 26.—Sparked Area, with and without corona. Corona removed by lightly rubbing with damp polishing cloth. $\times 4$.

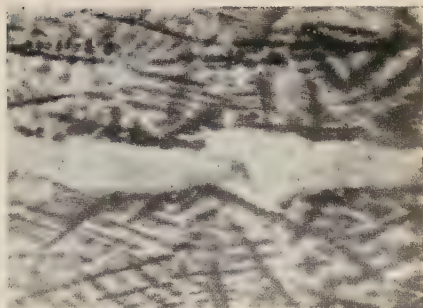


FIG. 27.—Macrostructure of Sample D. $\times 1.6$.

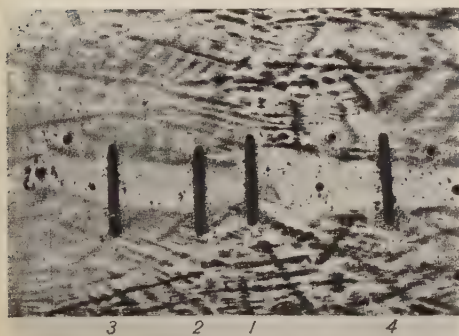


FIG. 28.—Displacement of Traverse Across Sample D. $\times 1.6$.



FIG. 29.—Traverse Across Inset Steel Bar. $\times 4$.

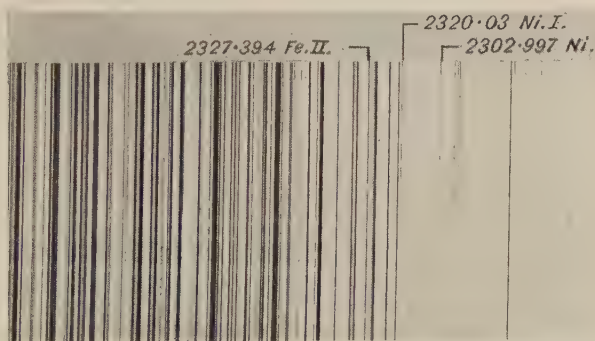


FIG. 30.—Spectrogram from Spark Traverse of Inset Steel Bar. $\times 0.8$.

[Convey and Oldfield.]

content of nickel-chromium-molybdenum steels. It is hoped that a critical consideration of carbon determination will be presented in a later paper, as further work is under way to examine the effect, if any, of the physical condition of the steel with respect to carbon emission.

Standardisation of the Air-Blast-Spark-Traverse Method.

Four carbon steels were traversed, and Fig. 11 illustrates the standard calibration curve relating the log ratio of the carbon spectral-line 2296·8 Å to the iron line Fe 2311·2 Å to the percentage of carbon present as obtained from the results. Each point on the curve is the average of thirty spectral-line density readings. This standard calibration curve exhibits a good variation in the spectral-line density with respect to the changes in carbon content between 0·15% and 0·95%.

The standard steels were similarly traversed, and calibration curves obtained for the elements manganese, nickel, chromium, molybdenum, vanadium and silicon. The spectral line pairs used were those given in Table VII.

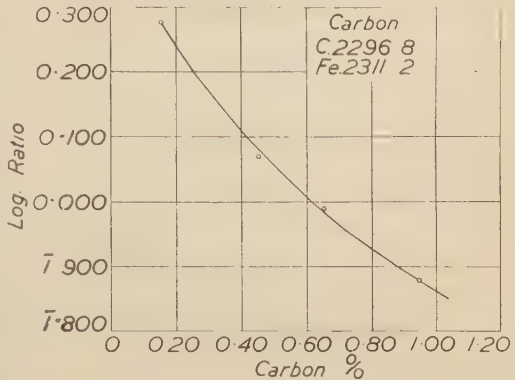


FIG. 11.—Carbon Calibration Curve.

TABLE VII.—Spectral-Line Pairs.

Element.	Classification.	Wave-Length. Å.	Composition Range. %.
Silicon	Si.I.	2881·578	0·05–0·60
	Fe.I.	2874·172	
Manganese	Mn	2933·063	0·05–1·00
	Fe.I.	2936·905	
	Ni.II.	2416·138	
Nickel	Fe.II.	2415·063	0·05–1·50
	Ni.II.	2312·916	
	Fe.II.	2312·034	1·00–5·00
	Cr.II.	2677·159	
Chromium	Fe.I.	2679·062	0·05–1·50
	Mo.II.	2816·154	
Molybdenum	Fe.II.	2813·613	0·05–1·00
	V.II.	2908·817	
Vanadium	Fe.I.	2912·158	0·05–0·50
	C.III.	2296·89	
Carbon	Fe	2311·288	0·15–0·95

Fig. 12 represents the vanadium calibration curve, produced from nine standard steels obtained through the generous co-operation of several Sheffield firms, and is a typical example of the type of calibration curve obtained.

PERFORMANCE TESTS.

In order to justify the method, rigorous tests were made; in addition to the steel sample C, three specially prepared well-worked bars of steel of

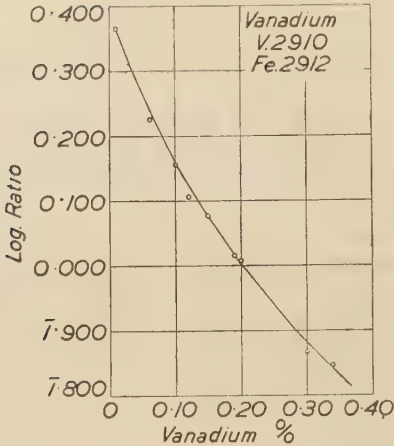


FIG. 12.—Vanadium Calibration Curve.

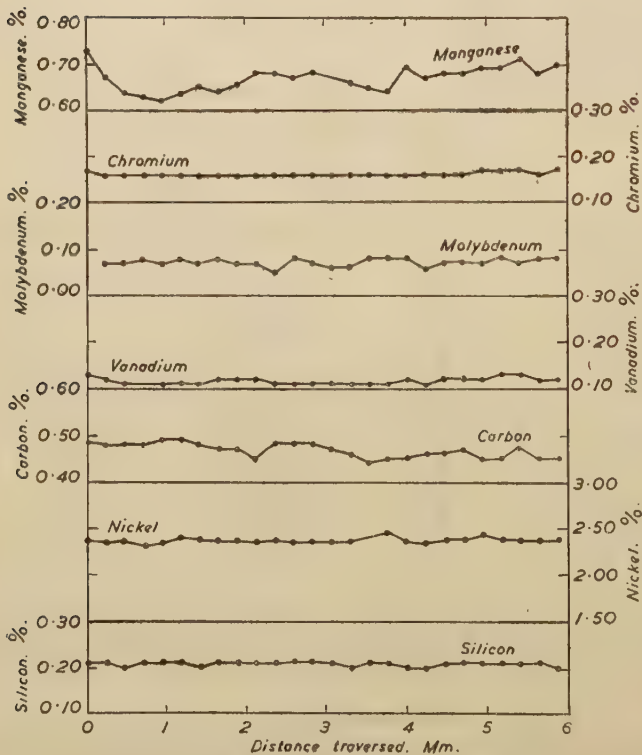


FIG. 13.—Analysis of Well-Worked Steel Bar No. 1.

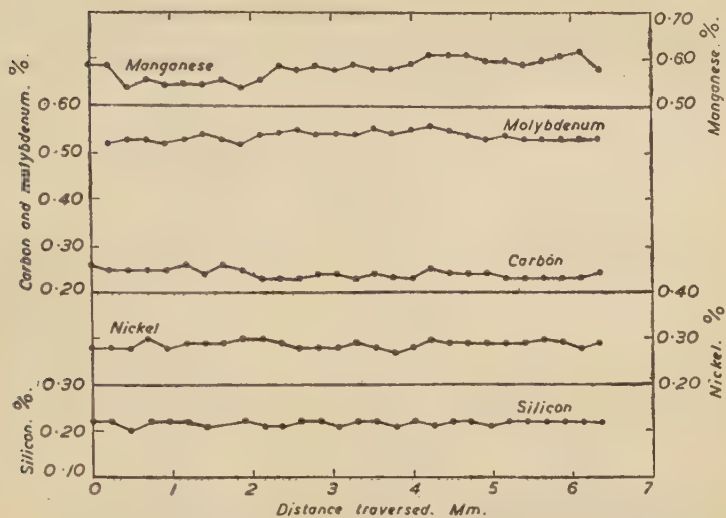


FIG. 14.—Analysis of Well-Worked Steel Bar No. 2.

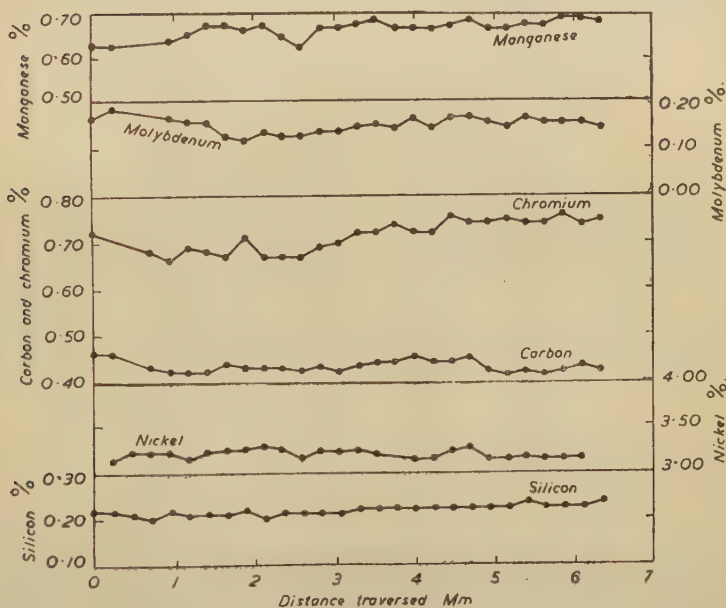


FIG. 15.—Analysis of Well-Worked Steel Bar No. 3.

different composition were traversed. These samples were all relatively homogeneous. Figs. 13, 14 and 15 illustrate the results and establish the claim of homogeneity of content. Table VIII. is a comparison of the chemical analyses and the average spectro-analyses of the three bars.

TABLE VIII.—*Results of Chemical and Spectral Analyses of Three Steel Bars.*

Method of Analysis.	Si. %.	Mn. %.	Ni. %.	Cr. %.	Mo. %.	C. %.	V. %.
<i>Steel Sample 1.</i>							
Spectral . .	0.21	0.67	2.37	0.16	0.07	0.47	0.11
Average deviation . .	±0.002	±0.02	±0.02	±0.002	±0.008	±0.01	±0.008
Chemical . .	0.21	0.66	2.40	0.15	0.07	0.45	0.12
<i>Steel Sample 2.</i>							
Spectral . .	0.22	0.58	0.29	...	0.53	0.24	...
Average deviation . .	±0.003	±0.02	±0.006	...	±0.01	±0.01	...
Chemical . .	0.23	0.61	0.23	...	0.52	0.25	...
<i>Steel Sample 3.</i>							
Spectral . .	0.22	0.67	3.20	0.71	0.16	0.43	...
Average deviation . .	±0.005	±0.01	±0.05	±0.03	±0.01	±0.01	...
Chemical . .	0.21	0.64	3.24	0.64	0.09	0.43	...

Another test was made on the previously mentioned inset bar, and the results are given in Table IX.

TABLE IX.—*Results of Traverse Across Inset Bar.*

Ni. %.	Cr. %.	Mo. %.	C. %.
2.51	0.86	0.66	0.26
2.51	0.85	0.68	0.27
2.51	0.84	0.68	0.27
2.48	0.86	0.66	0.28
2.55	0.81	0.66	0.27
2.55	0.86	0.68	0.27
2.51	0.85	0.66	0.27
2.49	0.84	0.66	0.27
2.56	0.82	0.67	0.28
2.49	0.80	0.66	0.29
2.43	0.79	0.63	0.29
2.34	0.77	0.63	0.29
1.85	0.67	0.54	0.27
0.69	0.30	0.25	0.15
0.10	0.15	0.06	0.05
0.05	0.15	0.04	0.05
0.05	0.16	...	0.05
0.07	0.16	...	0.05
0.05	0.16	...	0.05

The results of Table IX. are plotted graphically in Fig. 16. Fig. 29 illustrates the crater with respect to the inset bar and Fig. 30 a portion of the spectrogram as obtained from this traverse. The results as presented in Fig. 16 and Fig. 30 give a critical measure of the sensitivity of the method for the detection of differences in composition along the path of the traverse.

This test was repeated, but the traverse was made in a direction opposite to the one above. The results were as expected, and were quite similar to those given in Table IX. and Fig. 16.

With this evidence to confirm the method, tests were made on the steel samples *A*, *B* and *D*. The percentage contents observed for the elements silicon, nickel, manganese, chromium, molybdenum and vanadium con-

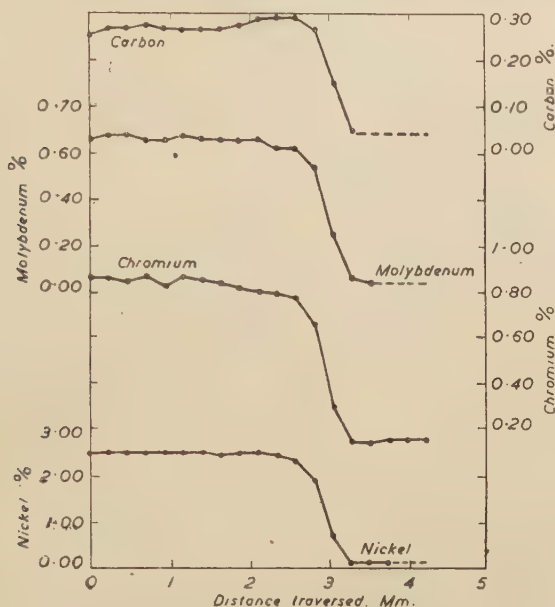


FIG. 16.—Analysis of Inset Steel Bar.

firmed those obtained by the traverse-spark method without air blast and the spot-spark method. However, there is now the addition of the analysis of the carbon variation across the segregates. Typical examples of segregate analysis in steel sample *D* are given in Figs. 17, 18, 19 and 20, and in steel sample *A*, in Fig. 21.

It is hoped that this paper will be followed by a detailed and critical consideration of the sensitivity and applicability of the method to other metallurgical problems, such as the analysis of inclusions and welded structures.

Acknowledgments.

The authors wish to express their appreciation of the encouragement which they have received from Mr. Barker, Superintending Scientist in the Bragg Laboratory, throughout the preparation of this paper, and for the facilities which he has placed at their disposal. They also wish to thank all those who have kindly assisted them in this work, especially Mr. J. Cross and Mr. G. P. Mitchell. Finally, their thanks are due to the Director of Scientific Research, Admiralty, for permission to publish the paper.

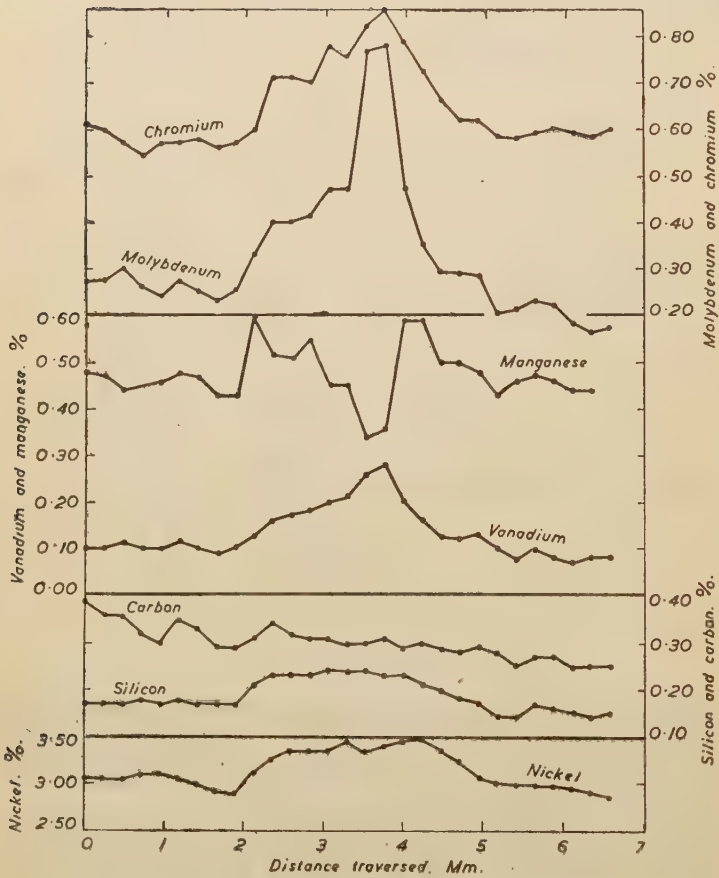


FIG. 17.—Analysis of Sample D, traverse (a).

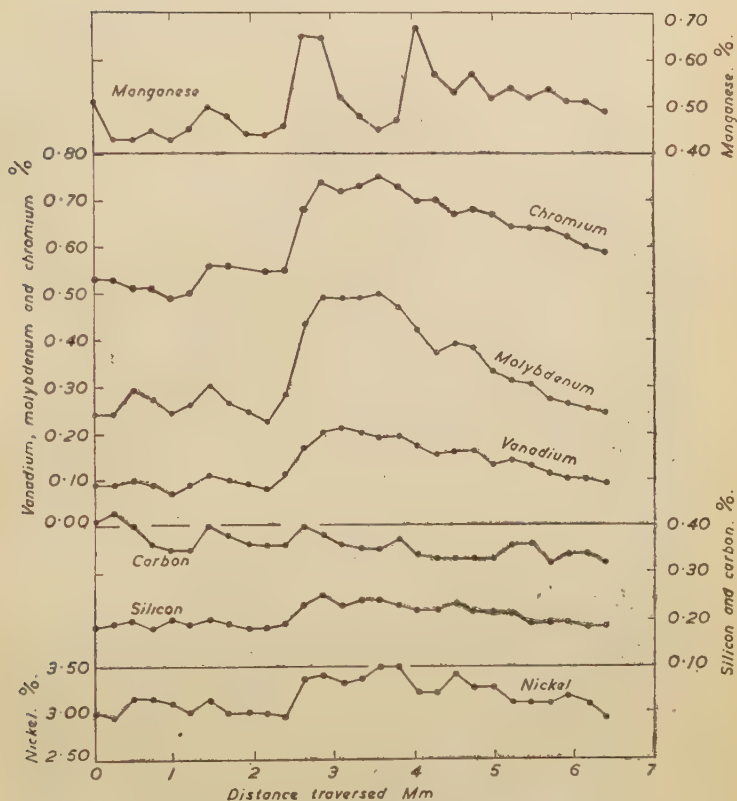


FIG. 18.—Analysis of Sample D, traverse (b).

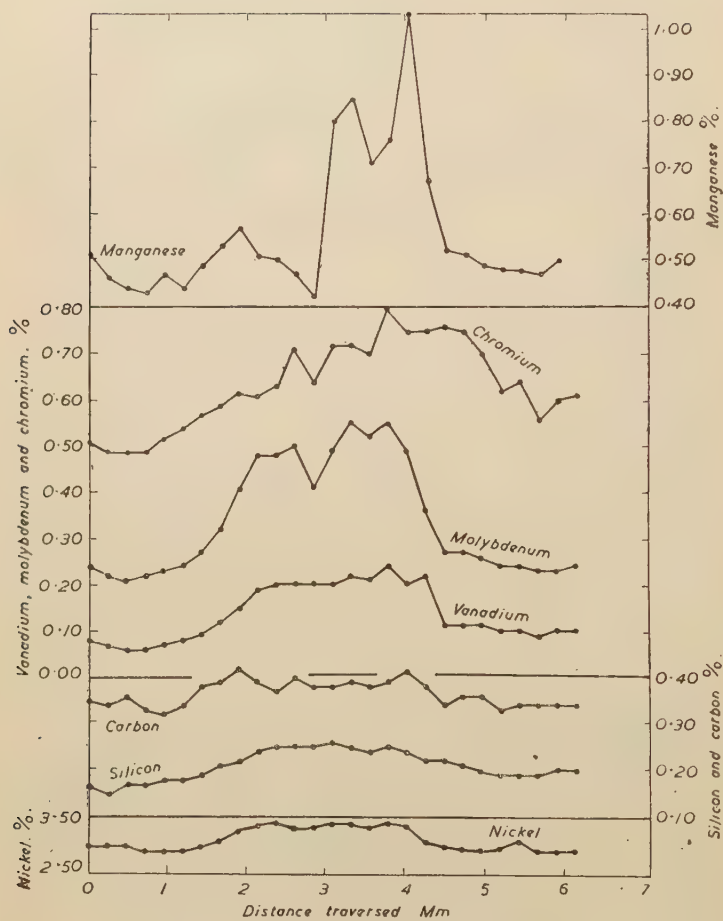


FIG. 19.—Analysis of Sample D, traverse (c).

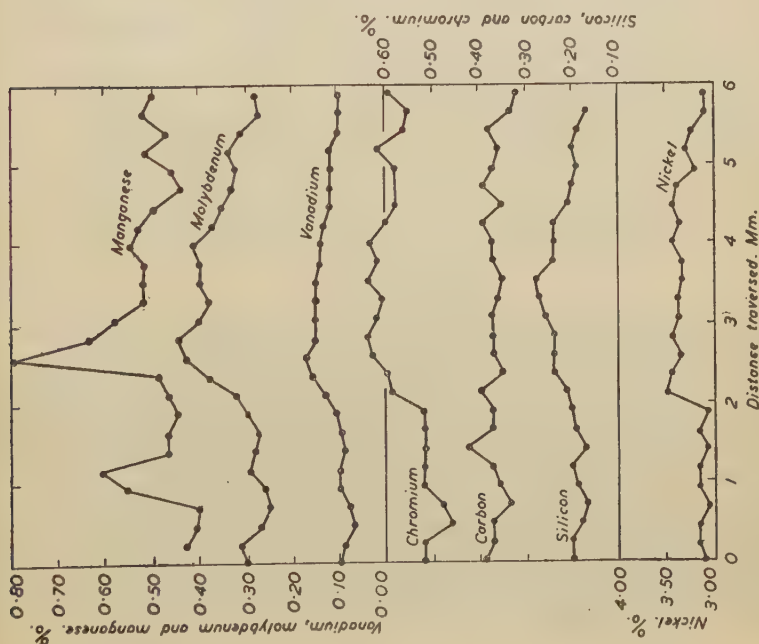


Fig. 20.—Analysis of Sample D, transverse (d).

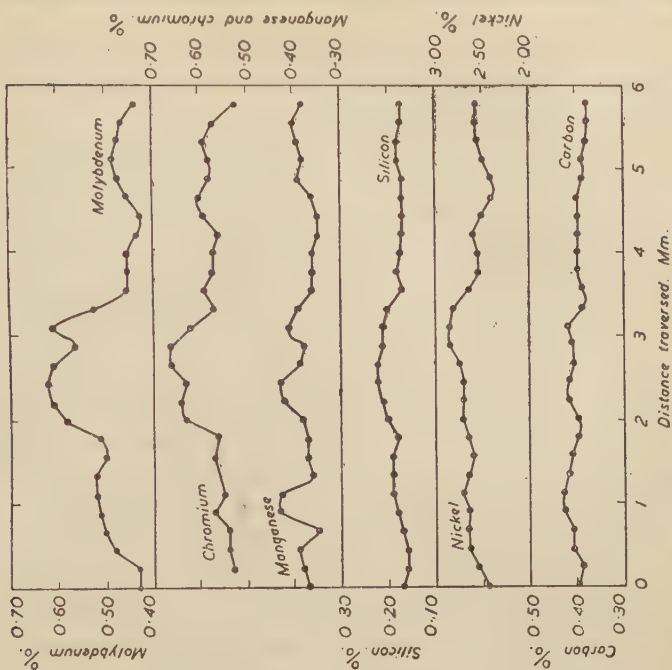


Fig. 21.—Analysis of Sample A.

REFERENCES.

- (1) TWYMAN : "The Spectrochemical Analysis of Metals and Alloys." London, 1941 : Charles Griffin and Co., Ltd.
- (2) MASSACHUSETTS INSTITUTE OF TECHNOLOGY :
 "Proceedings of the Fifth Summer Conference on Spectroscopy and its Applications," 1938.
 "Proceedings of the Sixth Summer Conference on Spectroscopy and its Applications," 1939.
 "Proceedings of the Seventh Summer Conference on Spectroscopy and its Applications," 1940.
 New York and London : John Wiley and Sons, Inc.; Chapman and Hall, Ltd.
- (3) KAISER : *Zeitschrift für technische Physik*, 1936, vol. 17, p. 227.
- (4) GERLACH and SCHWEITZER : "Foundations and Methods of Chemical Analysis by the Emission Spectrum." London, 1931 : Adam Hilger, Ltd.
- (5) BRODE : "Chemical Spectroscopy." New York and London, 1939 : John Wiley and Sons, Inc.; Chapman and Hall, Ltd.
- (6) SMITH : "Bibliography of Spectrochemical Analysis," second edition. London, 1940 : British Non-Ferrous Metals Research Association.
- (7) SCRIBNER : *Journal of Research of the National Bureau of Standards*, 1942, vol. 28, Feb., p. 165.
- (8) CHURCHILL and CHURCHILL : *Journal of the Optical Society of America*, 1941, vol. 31, Oct., p. 611.
- (9) BARKER : *Journal of The Iron and Steel Institute*, 1939, No. I., p. 211 p.
- (10) BARKER, CONVEY and OLDFIELD : *Journal of The Iron and Steel Institute*, 1941, No. II., p. 183 p.
- (11) THANHEISER and HEYES : *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1941, vol. 23, No. 3, p. 31; *Archiv für das Eisenhüttenwesen*, 1941, vol. 14, May, p. 543.
- (12) SCHEIBE and MARTIN : *Spectrochimica Acta*, 1939, vol. 1 (1), p. 47.
- (13) MURRAY, GETTYS and ASHLEY : *Journal of the Optical Society of America*, 1941, vol. 31, June, p. 433.
- (14) LANGSTROTH and BROWN : *Canadian Journal of Research*, 1942, vol. 20, No. 10, Section A, p. 173.
- (15) SEDOV : *Zavodskaya Laboratoriya*, 1939, vol. 8, p. 1112.
- (16) LANGSTROTH and McRAE : *Canadian Journal of Research*, 1938, vol. 16, No. 1, Section A, p. 17; No. 3, Section A, p. 61.
- (17) ROLLWAGEN : *Spectrochimica Acta*, 1939, vol. 1, No. 1, p. 66.
- (18) EMERY and BOOTH : *Industrial and Engineering Chemistry*, 1935, *Analytical Edition*, vol. 7, No. 6, Nov. 15, p. 419.
- (19) GAITERER and JUNKES : *Ricerche Spettroscopiche*, 1938, vol. 1, p. 1.
- (20) HARRISON : "Massachusetts Institute of Technology Wavelength Tables." New York, 1939 : John Wiley and Sons, Inc.

DISCUSSION.

Dr. J. H. WHITELEY (Consett Iron Co., Ltd., Consett, Co. Durham) : The investigation described in the paper is of the greatest importance in the study of steel segregates and I think the authors are entitled to high praise for a very fine piece of work. They have found, in the first place, that segregation can occur within a segregate, a thing which I have often inferred from the uneven appearance of a segregate in a prepared specimen after it has been etched and then very lightly polished again. An examination of the graphs given in the paper shows that the chromium and vanadium contents of the segregate change together, since in most cases the curves are roughly parallel. The molybdenum variations are not so well in step, while the manganese increments seem to have no relation to those of the above three elements. That may well be due to the presence of MnS in the segregates and hence it cannot as yet be said that manganese segregates except as MnS.

I would next remark that the three separate analyses of the segregate in steel *A* are not in very good agreement as can be seen from the following :

Segregate in—	Mn, %.	Ni, %.	Cr, %.	Mo, %.
Table II.	0.55	2.92	0.68	0.62
Table III. (average)	0.50	2.60	0.71	0.72
Table V. (average of last 17 results)	0.39	2.79	0.63	0.51

Were these analyses taken from the same segregate and, if so, how do the authors explain the differences? As a matter of interest I have also recorded the average of the three averages shown above, and, for comparison, the analysis of the non-segregate as shown in Table II. :

	Mn, %.	Ni, %.	Cr, %.	Mo, %.
Average of segregates	0.48	2.77	0.67	0.62
Non-segregate, Table II.	0.47	2.68	0.59	0.40

The figures seem to suggest that a segregation of manganese and nickel does not take place in general but only within the segregate areas.

Another point I would mention is that the segregates depicted in Figs. 22, 23, and 27 are very sharply defined and yet that apparently sudden change in composition is not as a rule evident in the graphs. Take, for example, the four traverses of sample *D* given in Figs. 7 to 10; one might expect the slope of the curves where the segregate begins and ends to be as steep as the slope in the curve for the inset bar shown in Fig. 16, but that is seldom the case. It will be of interest to have the authors' opinion on that matter. I think the clarity of the paper would be increased if they would explain more fully how it is that the inset-bar curve does not show a steeper fall.

The authors are to be specially congratulated on having overcome the difficulties in the spectrographic estimation of carbon in steel. I was surprised to see, however, that they found little or no evidence of any carbon segregation in the alloy steels that they have examined, for carbon is one of the most segregating elements. Now, when ferrite is precipitated in quantity, in slowly-cooled ordinary steels, most of the carbon in the segregate moves out as the A_1 point is approached and the segregate is then surrounded by a carbon-rich border. At any rate that takes place in rolled products and also in steel castings. Since there is no indication of such an action in the graphs it must be concluded that the carbon has remained *in situ*. Apparently, therefore, in this particular type of steel, carbon does not segregate, and if that is really the case the harmful effect of segregation will be greatly diminished. Clearly, there is room for much further investigation and I hope the authors will be able to continue the good work.

Dr. W. J. WRAŻEJ (Imperial College of Science and Technology, London): I should like to say how much I appreciate the opportunity of hearing the authors' method presented for discussion. I can truthfully say that every one of us who has been engaged in steel production and control encounters every day many questions about inclusions and segregates. There is no argument about whether the segregates are permitted or not; the main point is whether or not the kind of segregate is harmful. One question remains for the metallurgists, namely, whether the impurities can be avoided, and in what way. I have often been in a very difficult position, having found so many kinds of segregations and inclusions—say, in good structural low-alloy, commonly used nickel-chromium-molybdenum steels—and although such segregations may not be very numerous they were said to be harmful to the responsible parts.

There were many arguments and much discussion about their chemical

composition, and the various opinions expressed were really without any basic foundation. I know that the information which the steelmaker requires, in order to find a remedy for such failures, is as to what kinds of impurities are present, and, in particular cases, what kind of chemical composition they possess. The classical chemical method, as we know, gives the composition of the total amount of impurities in the sample, but not the composition of the distributed impurities which can be observed at high magnification under a microscope. I sincerely hope, therefore, that a solution to this question will be found in the beautifully delicate method presented in this paper.

Dr. C. H. DESCH, F.R.S. (President-Elect): The whole industry is tremendously indebted to the work which the Bragg Laboratory at Sheffield has done in the improvement of analytical methods, and particularly the spectrographic methods of analysis. Spectrographic methods have been used for a long time and developed in many countries, but the technique developed in the Bragg Laboratory is so far in advance of anything to be found anywhere else that it has made a complete change in our methods of analysing the more difficult kinds of steel and the more difficult cases that arise in the examination of a particular steel.

We have for a long time wanted some means of determining variation of composition over a small range within a steel, as, for example, in examining dendritic structures. About sixteen years ago in Sheffield, Dr. Jenkin and I were working on diffusion in metals, and we tried a method of studying diffusion by which, taking cupro-nickel as an example, among other things we studied the variation of composition in a dendrite in cupro-nickel. During the process of differential freezing one does not reach equilibrium, and it takes a very long time indeed to reach a homogeneous alloy. We wanted to know the range of composition in the dendrites in the alloy which was not homogeneous. The central core of a dendrite is richer in nickel, and round the border it is richer in copper, and the one shades very gradually into the other.

The method which we adopted was to make up a series of alloys of copper and nickel, very carefully produced and annealed until quite homogeneous; a series differing in steps of 10% from pure copper to pure nickel was prepared, and little blocks of these were made up into a composite block. After polishing the surface, we immersed it in a particular reagent which attacked the copper-rich portions more readily than the others; and we would find that, say, Nos. 1, 2, 3, and 4, and none beyond that, were etched in the course of a certain number of seconds. With a longer period it would go further along, and so on. At the same time, we would etch the cupro-nickel specimen showing dendritic structure and find that the etching extended from the outside a little way towards the core, but did not reach the centre. By doing a series of steps, of successive etchings, we were able to plot the concentration gradient within a dendrite. The work was never published, though I did some further work on it afterwards at the National Physical Laboratory, and it was communicated to the Ingot Committee.

The authors' traversing method with the spark gives a very much simpler means of arriving at the same result. It is quite an important question in the study of alloys, not merely of steels, to know what is the actual concentration gradient within a dendrite, and this seems to me to be by far the easiest method of studying it. I am sure that as the work goes on the technique will be still further improved, so as to use even a finer spark than is used at present; but the ingenuity shown in this work is so great that we must be grateful to the authors for having developed such a beautiful method, which can be applied in a laboratory equipped for spectro-

graphic work, as so many are now, and which will enable us to obtain results of the highest value.

Mr. F. W. J. GARTON (Chemical Inspection Department, Ministry of Supply, Bolton) : I shall confine my remarks to the carbon determination. For nearly a year now I have been working on the development of a spectrographic method for the determination of carbon on lines somewhat similar to those described by the authors, but using stationary electrodes and plate, and in the early stages I had considerable help from them. In certain respects, however, my findings differ from those of the authors, and I should like to put certain questions to them.

In the first place, the carbon line which they have chosen is a high-energy line. It is due to doubly-ionized carbon having an excitation potential of 53.5 V., and, according to the authors, the only iron line with which it was possible to compare it is due to singly-ionized iron. I think that the energy associated with that type of line is approximately 13 V., though I am not sure whether my information is correct. The authors remark in the paper that they have observed iron lines of higher energy levels. Have they made any attempt to use one of these higher-energy-level lines, and in particular Fe.III. 2295.859 which is closely adjacent to the carbon line? I have made comparative tests of that line and the Fe 2311.2 Å line which the authors use, and have found that the former gives superior reproducibility. It is, however, much fainter, and it is possible that the density of that line is insufficient in these trace experiments. It is equal in intensity to the carbon line at about 0.15% of carbon.

The second point is the authors' use of a very narrow analytical gap (0.3–0.4 mm.). It would be interesting to have details as to how accurately that gap can be maintained during the experiment, what steps the authors take to ensure that the surface of the specimen travels exactly parallel to the stage on which it is mounted, and whether they have any information regarding the influence of the gap width or variation of the gap width upon the carbon density.

The authors use an air blast and have tried air pressures of from 0.5 to, I think, 8 in. For practical purposes, that needs to be translated into actual air velocity. Can they say to what actual velocity that corresponds, and whether the velocity corresponding to the 0.5-in. pressure which they used is sufficient to sweep the gap completely during the passage of the individual discharges?

They refer in the paper to the falling-off of the apparent carbon content in the absence of an air blast. In a conversation which I had with Dr. Convey, he mentioned that the falling-off was comparatively sudden and appeared at irregular intervals after switching on the spark. I wonder whether he could give any further information about that, and also whether he could say to what level the carbon content falls off? My own experiments have shown that with either method of sparking the falling-off is not very serious after the first few seconds, and is not more than is normally met with in the case of what is known as the "pre-spark period," during which the intensities of the lines of most elements fall off. I have found, however, that his statement about the enhanced intensity with air blast is definitely confirmed. I have, furthermore, sparked steel in different atmospheres (*i.e.*, different gases), and found that in every case that I have tried so far the influence of the blast is what one would expect, to increase the intensity of the carbon line; but I do not confirm the authors' point that in the absence of air blast the carbon line falls off seriously in intensity.

I should like to ask whether the authors have taken account of the possible effect of atmospheric CO₂ in their carbon experiments. I have recently done some work on that myself, and I have found that the variation

of atmospheric CO_2 such as one would get in a normal laboratory at different times of the day is sufficient to affect the carbon content in the second decimal place, and might modify it by 0.02 or 0.03% of carbon. Furthermore, the effect of the spectrographic operator himself breathing on or near the apparatus is likely to be very serious. In point of fact, this method of sparking is a sensitive method for the detection of atmospheric CO_2 and amounts as low as 0.01% can be detected.

My last point is a practical suggestion to the authors. I found difficulty in obtaining even density of lines when using the small spark gap close up to the slit; there was a tendency, even when great care was used in centring, to get the line tapering from top to bottom. The use of a short-focus quartz lens close up to the slit, in the same way that the normal quartz lens is used, to throw an image of the spark on the collimating lens, will even out the intensity completely and make it possible to use a much longer line and maintain the same line intensity.

Mr. A. S. NICKELSON (Chemical Inspection Department, Ministry of Supply, Woolwich): The paper is of considerable interest to all spectrographers engaged on metallurgical problems. I should like some further information from the authors on the question of plate calibration. My experience of other work in connection with non-ferrous alloys has shown that there are serious difficulties in obtaining reproducibility, due mainly to slight differences in plates and developing conditions. Is $1\frac{1}{2}$ min. development sufficient to give an evenly-developed plate? Otherwise there will be some difficulty in correlating results from plate to plate. The authors, no doubt, have this question of plate calibration in mind, for consideration in a later paper.

CORRESPONDENCE.

(Figs. A to E = Plates XLVIIIa and XLVIIIb.)

Dr. R. V. RILEY (Messrs. Bradley and Foster, Ltd., Darlaston) wrote: The authors are to be congratulated upon their adaptation of the spectrographical method to the analysis of steel segregates. Their method is evidently one capable of wide application and could be used in the study of microsegregation and minor heterogeneity in a number of types of ferrous alloys. The ingenious mechanical device used for moving the specimen and the photographic plate simultaneously is evidently the research laboratory's own work and is the more highly commendable on that account.

It is interesting to note that the authors have chosen as their line pairs in the air-blast spark-traverse method, lines of wavelength generally lower than those normally adopted in ferrous spectrographic analysis. Is it to be presumed that this has been done in order to accommodate on the same plate the line pair for the estimation of carbon? Have the authors in adopting these line pairs satisfied themselves that the γ curve of the Kodak B.10 plate was satisfactory for their purpose in this range?

No mention is made in the paper of any attempt at photographic-emulsion calibration, and yet from Table VII. it will be noted that in some cases elements over a considerable percentage range are determined, using only one, or at the most two, line pairs. It is to be expected, for instance, that the recorded blackness of the weak nickel line 2416.138 Å., for percentages of less than 0.10, will be well below the range over which blackness values are linearly proportional to the true emission-line intensity.

The spectrogram shown in Fig. 30 reveals the presence of a somewhat indistinct banding over the lower half of the photograph. Prompted by

curiosity and in view of the authors' assurance on p. 482 P, first paragraph, that the "continuity and smooth running of the mechanical functioning of the assembled apparatus" leads to "clarity and uniformity of the spectral lines throughout their length"—as in the case of the spectrogram shown in Fig. 24—some thought has been given to possible causes for this irregularity in the spectrogram in Fig. 30. Careful examination of this spectrogram shows that the alternate light and dark appearance was caused by variations in density of some of the spectral lines which in the main are iron lines. If one assumes a steady rate of traverse across the inset-steel-bar specimen these variations in intensity could only result from variations in the electrical conditions at the spark such as might be caused, for example, by local variations in gap width. The frequency of the banding in Fig. 30 appears to bear some relationship to the machining or grinding irregularities in the mild-steel part of the specimen as shown in Fig. 29. The two deepest markings which cross the spark traverse in the mild-steel zone of the inset-steel-bar specimen appear to have roughly the same relative positions as the two main bands in the lower half of the spectrum in Fig. 30. Perhaps this relationship is merely coincidental, but it would be helpful if the authors could look into the matter and then perhaps continue the graph shown in Fig. 16 to the full 6.5-mm. traverse of the spark path illustrated in Fig. 29.

Mr. W. J. POEHLMAN (Messrs. A. O. Smith Corporation, Wisconsin, U.S.A.) wrote: This is indeed a most interesting, enlightening, and timely paper. We have been making satisfactory analyses on steel segregates, inclusions, penetrators, cracks, and welded structures, including weld-metal dilution, by using the spot-spark technique during the entire war production programme. However, the traverse-spark technique introduced by the authors promises to be of great value to those interested in steel. We attempted a few carbon tests, but obtained negative results in the little time that we could devote to the development of new techniques. The results obtained by the authors with their new method corroborate those of our laboratory on all elements except carbon. We made these analyses by placing one spot directly next to the other.

The conditions employed in our technique are given below. We use the A.C. spark for the major elements and the A.C. arc for the residual or minor elements when required. The instrument used is either a Hilger E.I. or Bausch and Lomb large littrow quartz spectrograph:

Wave band, Å.	.	.	.	.	.	2110-2759 and 2519-3558
Source	.	.	.	.	.	Spark. A.C. arc.
Voltage	.	.	.	.	.	35,000 V. 5000 V. peak.
Power	.	.	.	.	.	$\frac{3}{4}$ and $\frac{1}{2}$ kVA. 2.5 amp.
Inductance	.	.	.	.	.	Nil ...
Capacitance	.	.	.	.	.	0.007 μ F. ...
Analytical gap, mm.	.	.	.	.	.	1.0 1.0
Slit width, mm.	.	.	.	.	.	0.015 0.015
Upper electrode	.	.	.	.	.	Silver * S.P. graphite
Lower electrode	.	.	.	.	.	Sample, Sample.
Source to slit distance, in.	.	.	.	.	.	4 8
Exposure time, sec.	.	.	.	.	.	10-14 30
Plate	.	.	.	.	.	S.A. No. 1.
Developing	.	.	.	.	.	D.19-3 min.—70° F.
Fixing	.	.	.	.	.	X-ray-3 min.—70° F.
Washing	.	.	.	.	.	Running water, 15 min., distilled-water rinse, 1 min.

* The shape is similar to No. 6 described in Fig. 3 of the authors' previous paper, *Journal of The Iron and Steel Institute*, 1941, No. 11., p. 183 P. Other pure metals, including tungsten, have been used with negative results.

Fig. A shows a lamination in steel plate and the locations of some of the sparked and "arced" areas. The analyses and a description of the various areas investigated are presented below :

	Mn, %.	Si, %.	Ni, %.	Al, %.	Mo, %.	Cu, %.	Mg, %.	Ti, %.	Description of Area.
A.	1.25	0.04	...	...	...	...	...	...	Sound metal. Spark.
B.	...	...	0.01	Nil	0.01	0.019	Nil	Nil	Sound metal. A.C. arc.
C.	1.30	0.07	...	...	...	...	...	...	Tight lamination. Spark.
D.	...	...	0.01	0.05	0.01	0.02	Trace	Trace	Tight lamination. A.C. arc.
E.	1.41	0.39	...	...	...	...	...	...	Open lamination. Spark.
F.	...	...	0.01	0.01	0.02	0.03	Med.	Med.	Open lamination. A.C. arc.
G.	1.49	0.45	...	...	...	...	...	...	Surface of open lamination. Spark.
H.	...	...	0.015	+0.20	0.02	0.04	High	High	Surface of open lamination. A.C. arc.

In Fig. B inclusions in steel S.A.E. 4340 (plus vanadium) are shown. This is a transverse cross-section of a sample showing inclusions probably derived from furnace slag. Spectrographic investigation showed increased amounts of manganese, silicon, aluminium, and magnesium over those which were found in the sound metal. An example of porosity in the centre of a sample of wrought heat-resisting steel is given in Fig. C; the central pipe was porous and the metal was found to be high in iron, manganese, and silicon. Fig. D shows a lamination in a sample of S.A.E. 4340 (plus vanadium) steel plate, manufactured in the basic-electric furnace. The defect was found near a weld junction in the parent metal, and the material of the lamination was probably derived from furnace slag. In Fig. E two transverse samples of all-stainless weld-metal taken from a weld in $\frac{1}{2}$ -in. plate are shown in the as-received condition and after sparking. Details of the areas shown are as follows :

58A shows a badly corroded weld pass, and

58B layers of proper weld metal;

59A and 59B show all passes made with one kind of welding electrode—viz., 25% chromium, 12% nickel, plus columbium—using the same groove, but different locations.

The badly corroded pass (Fig. E, 58A) is due to the use of a 20% chromium, 12% nickel (plus columbium) welding electrode instead of the correct 25% chromium, 12% nickel (plus columbium) electrode.

The following spectrographic results are averages of four areas of the samples shown in the photographs :

	Mn, %.	Si, %.	Cr, %.	Ni, %.	Cb, %.	Cu, %.
58A	1.88	0.53	15.50	12.10	0.51	0.15
58B	1.30	0.68	19.80	11.07	0.75	0.18
59A	1.36	0.73	20.10	10.79	0.77	0.20
59B	1.34	0.71	19.96	10.84	0.74	0.19

Although we have been solving our problem by the spot-spark method we are interested in any new developments in spectrographic applications. Of particular interest is the analysis of the non-metallic elements, on which we hope to do some work.

The authors are to be congratulated on their ingenuity in this development of a new method, including the traversing mechanism by which they also obtained satisfactory results on the analysis of carbon. The clarity of their explanation of this technique is appreciated; however, a more detailed description of the traversing gear would be very helpful.

Furthermore, we wish to encourage the authors in their contemplated detailed and critical consideration of this method as applied to other metallurgical problems. Having spent considerable time on corrosion investigations, we would like to ask if the study of carbon migration phenomena in stainless steel has been attempted?

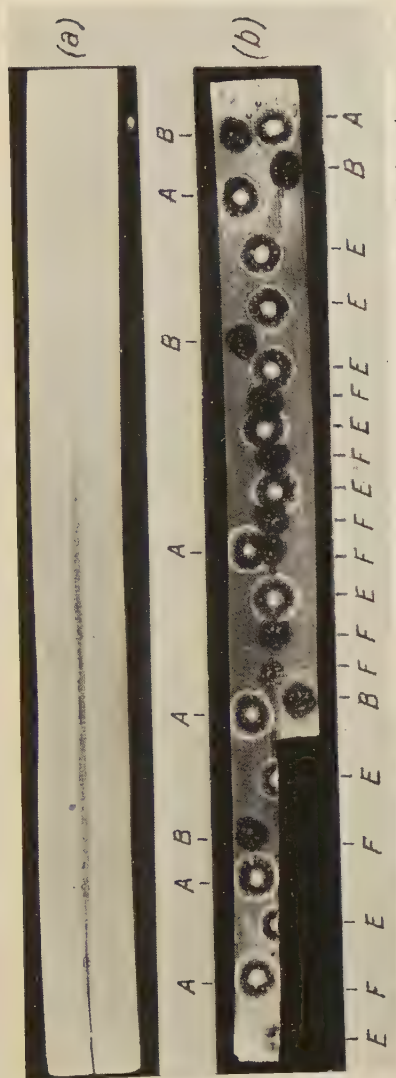


FIG. A.—Lamination in Steel Plate, showing (a) cross-section in the as-received condition, and (b) sparked and arced areas.

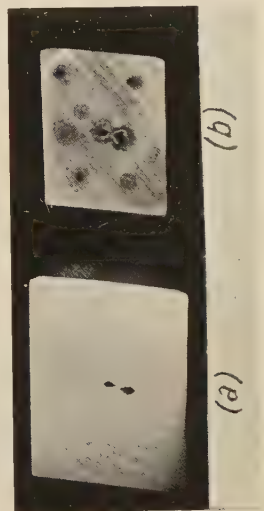


FIG. B.—Inclusions in S.A.E. 4340 (plus Vanadium) Steel, (a) as-received, (b) sparked areas.

(See Poehlman's contribution.)

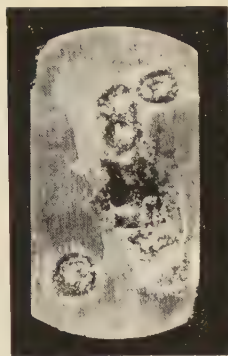


FIG. C.—Porosity at the Centre of 35% Chromium, 15% Nickel Heat-Resisting Steel.

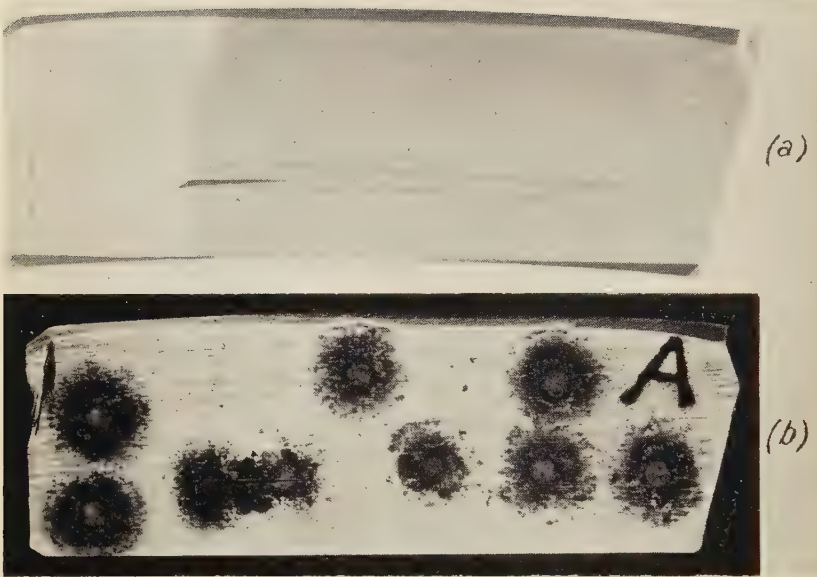


FIG. D.—Lamination in a Sample of S.A.E. 4340 (plus Vanadium) Steel Plate, (a) as-received, (b) sparked areas.

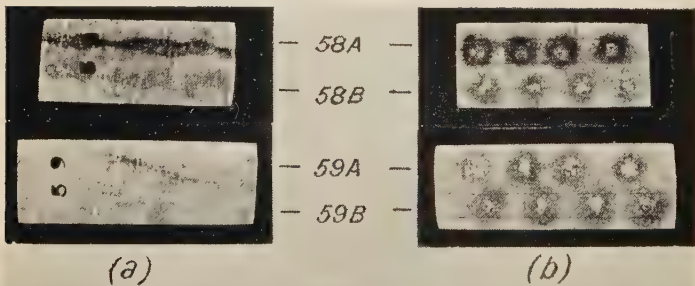


FIG. F.—Transverse Samples of All-Stainless Weld Metal (a) as-received, (b) sparked areas.

(See Poehlman's contribution.)

AUTHORS' REPLY.

The AUTHORS wrote in reply : We thank Dr. Whiteley for his constructive and enlightening discussion of the paper. In reply to his comments on Tables II., III. and V. asking for an explanation of the apparent discrepancies which appear to exist among repeated analyses on the same steel sample, these results were obtained at different dates over a period of two years. During this time the segregate had diminished considerably through repeated polishing and etching; as a result, the major-segregation content factors were reduced. In addition, Table V., as explained in the text, is not an absolute analysis, as the results were unstandardised and were obtained relative to calibration curves yielded by the spot technique; these results were quoted to show that the traverse technique was worthy of investigation.

That the inset-bar content curve does not show a steeper fall is due to what may be described as a dilution factor produced by the sparked crater possessing a definite area. If the sparked area were infinitely small then the content gradient would be perpendicular. In the case of the segregates, as compared with the inset bar, the results generally indicated that there is no sudden content change.

The carbon-rich border of a segregate mentioned by Dr. Whiteley has been detected in some steels. Fig. F illustrates this effect; the dotted line indicates the junction of two traverses.

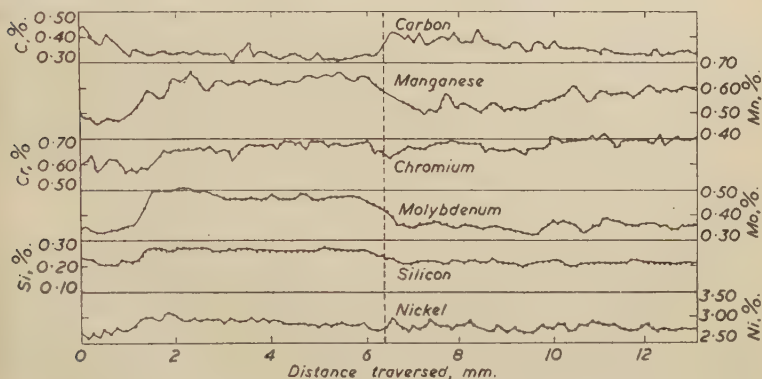


FIG. F.—Analysis of Ni-Cr-Mo Steel (two collateral traverses).

We sincerely appreciate the kind comments of Dr. Wrazej, which indicate the value of the method to the metallurgist.

Dr. Desch's instructive remarks on his early experiments in the diffusion of metals and his generous appreciation of the traverse spectrographic method gave us great satisfaction and will encourage us in our future work.

It is a pleasure for us to record our answers to the queries presented by Mr. Garton with respect to carbon determination. Under the experimental conditions adopted, which differ in many ways from those of Mr. Garton's technique, it was quite evident from early exposures that the Fe.III. 2295.859 was too weak for densitometric determinations. The obvious answer to the second point, on the analytical-gap stability during sparking, is well illustrated by the practical results on the homogeneous steel bars. Any spark-gap instability would demonstrate itself as a marked variation in the results, but the changes noted are all within the experimental error of the method.

We disagree with Mr. Garton's claim that for practical purposes the air pressures used should be translated into actual air velocities. It is sufficient to state the air pressure and the size of glass tubing orifice. No investigation has been carried out to see whether the spark gap is swept completely during a discharge, as such a point under the circumstances appears unnecessary.

Dr. Convey regrets if Mr. Garton has misinterpreted his remarks about the decrease in intensity of the carbon line C.III. 2296. There is quite a marked change in the carbon emission after the first few seconds, without the re-appearance at irregular intervals mentioned in Mr. Garton's remarks. This carbon emission without the air blast is so feeble that it lies below the threshold of reliable densitometry.

The effect of atmospheric CO_2 on carbon determinations has not been investigated, as such a correction has never been necessary. Results have been obtained both in the University of Sheffield and in the centre of the Sheffield works district at various times of the day and year, and the reproducibility has been excellent. As for the effect of the operator breathing on or near the apparatus, as a personal safety measure we do not stand too near the spark during an exposure.

The last point presented by Mr. Garton concerning the tapering of the spectral lines is easily overcome in our laboratory by the two-directional viewing of the spark gap in its location on the optical axis of the spectrograph; we have described this in an earlier paper.* The incorporation of a short-focus lens in front of the slit does not eradicate entirely the error of poor alignment but merely enhances the density of the spectrogram with an apparent correction of the wedge-shaped line.

In reply to Mr. Nicholson, we have found $1\frac{1}{2}$ min. development of Kodak B.10 plate sufficient to give even development. Later work in process of publication will demonstrate how several successive traverses were made on a series of plates and the reproducibility of the results was such that the content curves plotted from the results showed a remarkable continuity. In the comparison of spectrographic work in non-ferrous and ferrous analysis it is recognised that lack of spectral-source control is often misrepresented as non-reproducibility of the photographic aspect.

In replying to Dr. Riley, we wish to point out that the choice of low-wavelength lines was governed by the need to accommodate the carbon line C.III. 2296.89 on the same spectrogram as the spectral lines of the other alloying elements. The Kodak B.10 plate has proved a quite satisfactory medium for spectral recording in the adopted wavelength region. No photographic-emulsion calibration was found necessary, although for the low-percentage nickel determinations such calibration would probably increase the accuracy of the analysis and improve the determinations of the other elements.

The relationship between the banding shown in the spectrogram in Fig. 30 and the grinding marks on the steel specimen in Fig. 29 is quite accidental and the two features are not associated. Such spectrogram banding is always associated with microscopic faults in the silver electrodes. During sparking very small globules of silver form at the tip of the electrode; this alters the sparking conditions and the resulting spectral emission is decreased, producing the banding as exhibited in Fig. 30. If the banding were associated with the grinding marks on the specimen, then we should feel that very few spectrograms would be reliable. This is especially true of the inset bar mentioned in the paper, for in this case the spark traverses a junction of two metals. Fortunately the banding has not exhibited any spectral emission preference; all lines appear to be reduced in intensity to the same extent, hence the results are unaffected.

* *Journal of The Iron and Steel Institute*, 1941, No. II., p. 183 p.

The authors desire to express their appreciation of Mr. Poehlman's contribution, and are very gratified to learn of independent corroboration of their results. They also wish to thank him for the details of the spectrographic techniques which he has provided, and for the information concerning the analysis of inclusions and welds. We are not aware that the study of carbon migration in stainless steels has as yet been attempted by the traverse-spark technique. We hope, however, to have the opportunity of discussing the general applicability of the technique to metallurgical problems which involve the examination of minute surface areas in a future paper.

ANALYTICAL SURVEY OF A RIMMING-STEEL INGOT.*

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(Fig. 1 = Plate XLIX.)

SYNOPSIS.

A $5\frac{1}{2}$ -ton ingot of rimming steel containing 0.11% of carbon and 0.45% of manganese was sectioned along the vertical axis for analytical survey and sulphur-printing. The results of chemical analysis made with reference to the distribution of carbon, manganese, sulphur and phosphorus do not appear to indicate any significant departure from the known trend of variations of the segregating elements from the outside to the centre of the ingot and from the bottom to the top.

A Table giving theoretical carbon and oxygen percentages at the balanced composition, calculated according to the expression given by Binnie (*Journal of The Iron and Steel Institute*, 1942, No. II., p. 283 r), for some of the rimming-steel ingots of which data have been published was prepared. The theoretical carbon percentage at the balanced composition for the present ingot was calculated to be 0.0714%, 0.0875% and 0.101% at 1, 1.5 and 2 atm., respectively.

The average carbon content of the entire core was 0.17%, as compared with the ladle figure of 0.11%, and that of the rim zone was about 0.09%. The average carbon content of the ingot as a whole was 0.150%. Since this figure should normally be below the ladle-analysis figure, in view of the concept that the iron-oxide/carbon reaction is mainly responsible for a decrease in the carbon content of the rim zone, the inference is drawn that the ladle carbon content recorded was very low.

INTRODUCTION.

IN view of the interest that has recently been taken in the distribution of segregating elements in rimming steel ingots, with special attention to the verification of the Hultgren and Phragmén⁽¹⁾ balanced composition hypothesis, it was thought desirable to publish the results obtained several years ago (1932) on a rimming-steel tin-bar ingot of heat No. 23606 made at the duplex plant of the Tata Iron and Steel Co., Ltd., Jamshedpur, India. The ingot was sectioned along the vertical axis for analytical survey and sulphur printing. This paper is intended to supplement the known information on the subject of rimming-steel ingots.

Method of Sampling.

The structure of the split ingot and the positions of the drill holes (marked 1 to 87) are shown in Fig. 1. The drillings were taken from the zones representing 4, 9, 15, 18, 25, 35 and 50% of the width of the ingot, respectively. The analysis data are shown graphically in Figs. 2 to 6 by averaging the analysis figures from similar drill positions on either side of the vertical axis of the ingot. The ladle analysis of the heat was as follows: carbon, 0.11, 0.11, 0.12%; manganese, 0.45%; sulphur, 0.029%; phosphorus, 0.06%. The ingot was 74 in. long, 24 in. square at the bottom and $21\frac{1}{2}$ in. square at the top. The average ratio of the area of the rim to the core was 1.27.

* Received May 6, 1944.

Examination of the Results.

A fairly large mass of data showing the vertical and horizontal distribution of carbon, manganese, sulphur and phosphorus in rimming-steel ingots has been published in recent years, which indicates certain well-defined changes in composition from the bottom to the top of the ingot and from the edge to the centre of the core. The results presented here do not appear to indicate any significant departure from the known trend of variations.

Taking first the vertical variations, it appears that the carbon in the rim zone (Fig. 2) is practically uniform from the bottom to the top of the ingot. There is, however, a slight tendency for the carbon to decrease at the top. The average of the carbon determinations of both the outer and inner portions of the rim, *i.e.*, zones representing 4% and 9% of the ingot width, respectively, is 0.10% and is, therefore, about 90% of the ladle analysis figure. The lowest carbon content in the rim is 0.075% (average of positions 36 and 46), which is 68% of the ladle sampling determination. Regarding the distribution of manganese, sulphur and phosphorus, there is a distinct tendency for these elements to be higher in the lower part of the ingot than in the upper regions. Further, the inner zone of the rim, passing through 9% of the width of the ingot, shows lower percentages of carbon, manganese, sulphur, and phosphorus than does a similar zone near the surface of the ingot. The mean manganese figure near the outside of the rim at the bottom of the ingot is 17% above the ladle analysis. Except for a small peak at the middle of the ingot, it falls to the ladle sample value of 0.45% in the top region. Both the sulphur and the phosphorus in the outer part of the rim at the bottom of the ingot are 10–25% below the ladle figures, while at the top the decrease is of the order of 30–44%. The extent of the fall is greater for the phosphorus than for the sulphur.

At the junction of the rim and the core (Fig. 3), all the segregating elements increase from the bottom to the top of the ingot, this being more marked in case of carbon, sulphur and phosphorus than in that of manganese. Thus, the vertical variation in composition in the rim-core junction is the reverse of that in the rim itself. The average carbon of the junction zone is 0.165%, which is 50% higher than the ladle figure of 0.11%. At a point 75% above the bottom of the ingot, the carbon reaches a maximum figure of 0.205%. The average values of sulphur and phosphorus are 0.037% and 0.063%, respectively. This means that the mean values of sulphur and phosphorus in the zone of secondary blow-holes are 27% and 5% higher, respectively, than the ladle analysis figures. Thus, as usual, the degree of segregation of the sulphur is greater than that of the phosphorus. The maximum values for sulphur and phosphorus are 0.05% and 0.0805%, respectively, corresponding to an increase of 72% of the sulphur and 34% of the phosphorus above the ladle analysis figures. Further, both sulphur and phosphorus figures below 27% and 40% of the ingot height, respectively, are lower than the figures for the ladle analysis. Sulphur also shows some peaks corresponding to small segregations in the particular positions analysed. It is significant that the two peaks at 46% and 75% of the ingot height, coincide with those on the manganese curve. Attention may also be drawn to the general pattern of these curves (Fig. 3). They indicate that the maximum values for all the elements in the junction zone is reached at about 75% of the ingot height, after which there is a slight drop in the degree of segregation. Such a drop is conspicuously absent in the curves for the metal inside the junction (*see* Figs. 4 and 5). It is thought that, as a result of a normal sequence of events during rimming, the metal in the interior of the top quarter of the ingot remained molten for a relatively long time, and that

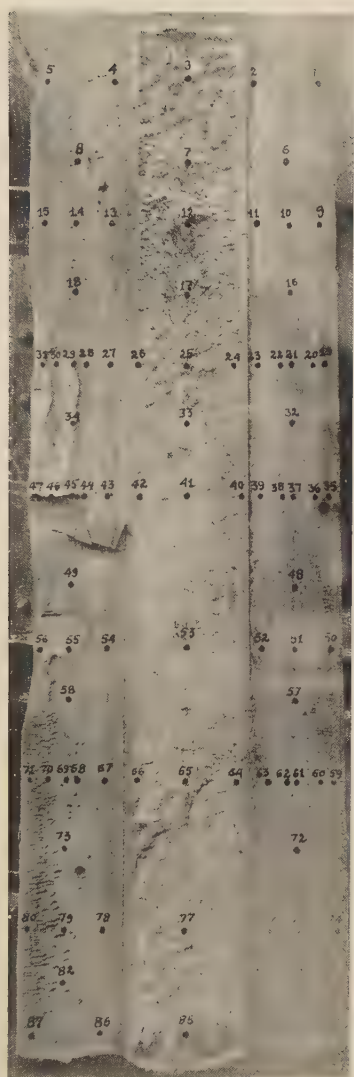


FIG. 1.—Structure of Split Ingot (No. 23606) with positions of drill holes marked.

[Vatchagandhy and Contractor.
[To face p. 510 p.]

the movement of the more fusible constituents, which were pushed both inwards and upwards by the advancing wall of the rim, decreased in the upward direction owing to the formation of a crust constituting a part of the

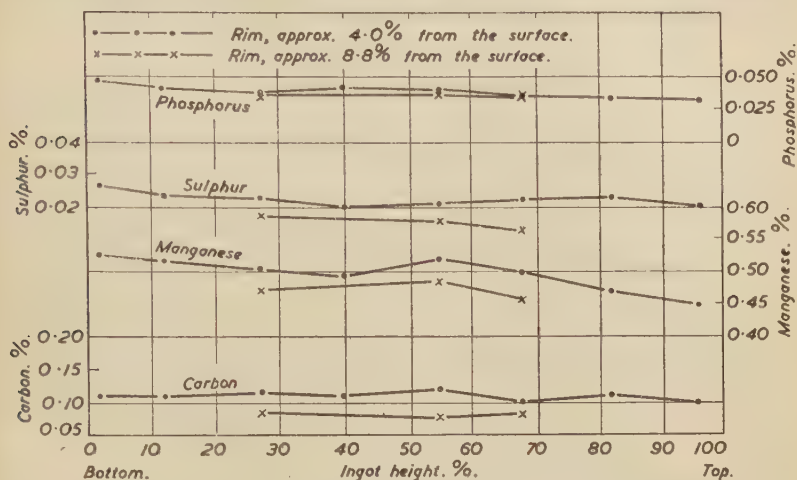


FIG. 2.—Longitudinal Section through the Rim Metal.

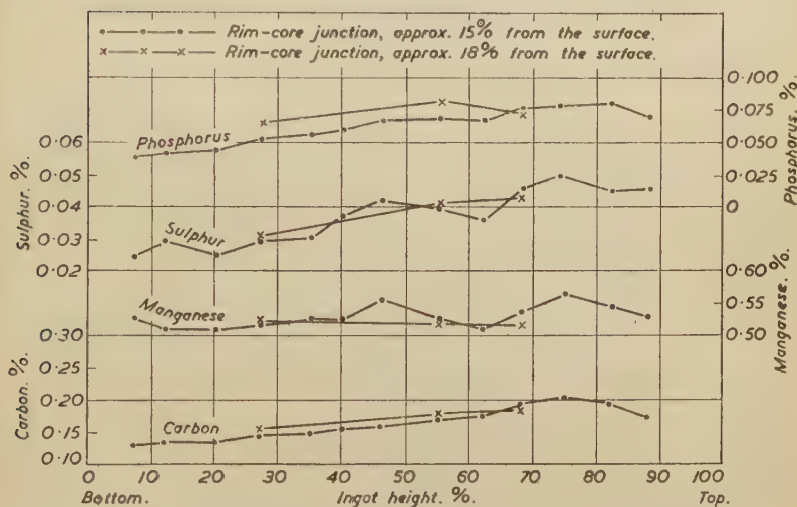


FIG. 3.—Longitudinal Section through the Rim-Core Junction Zone.

rim. The upward movement thus being slowed down, the metalloids in the junction zone at the top of the ingot were pushed inwards, *i.e.*, towards the "mushy" interior. This, it is presumed, resulted in a slight drop of the degree of segregation in the junction zone at above 75% of the ingot height. With regard to the manganese distribution, the degree of segre-

gation varies from 13–25% over the ladle analysis figure throughout the entire length of the ingot.

In the core representing 25% and 35% of the width of the ingot (Fig. 4), all the elements rise from the bottom to the top of the ingot and reach

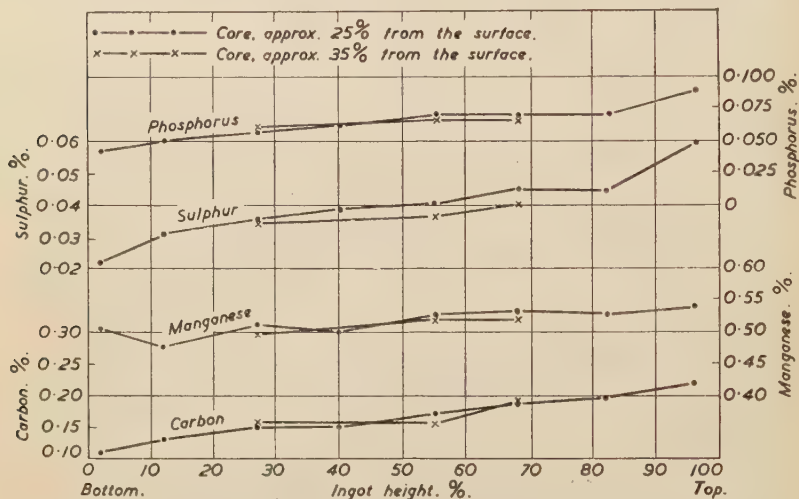


FIG. 4.—Longitudinal Section through the Core representing 25% and 35% of the width of the ingot.

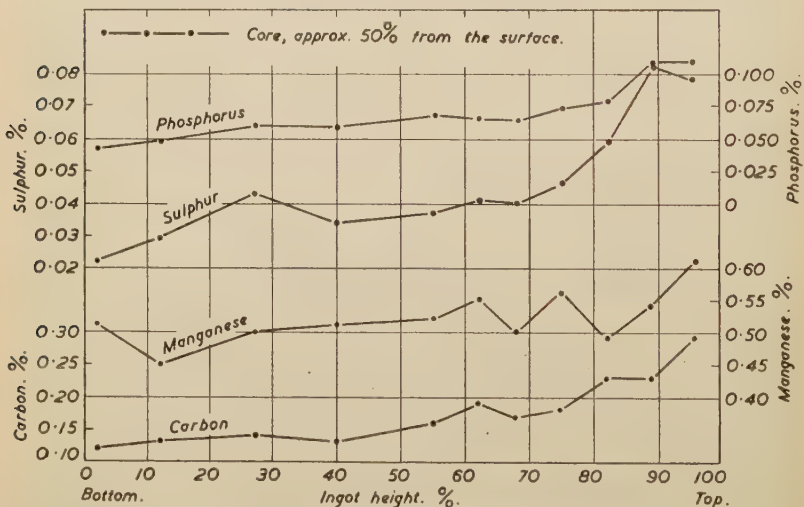


FIG. 5.—Longitudinal Section through the Centre of the Core.

their maximum at about 96% of the ingot height. The average carbon in this portion of the core is 0.165%, which is of the same order as the average carbon content of the junction zone. The other elements, as usual, are,

on an average, in lesser amounts than in the junction zone. The rise in sulphur is again more pronounced than that of phosphorus.

At the centre of the core (Fig. 5), the general analysis reveals a rise in carbon from the ladle figure of 0.11% to an average value of 0.18%. This corresponds to a rise of over 63% of the ladle analysis. Nowhere in the entire core of the ingot is the carbon content below the ladle figure. Up to 82% of the ingot height the rise in carbon, sulphur and phosphorus is gradual, except for a peak in the sulphur curve, after which the increase is rather rapid. This is obviously due to the increased concentration of the metalloids in the top 15% of the ingot. In the bottom half of the ingot the carbon is 10-25% above the ladle figure as compared with 50-150% in the upper half. Both sulphur and phosphorus reach their maximum at 88% of the ingot height. At this height the steel contains 0.082% of sulphur and 0.108% of phosphorus, as against the ladle figures of 0.029% and 0.06%, respectively. In the bottom of the ingot both sulphur and phosphorus are below the ladle figures by 24% and 30%, respectively. Whereas in the case of phosphorus there is practically no rise above the ladle figure up to a point about 50% from the bottom of the ingot, the sulphur content at this level is 24% above the ladle sample determination. The manganese curve is irregular, indicating heterogeneous distribution of this element in the central core. The degree of segregation varies from 13-35% above the ladle figure throughout the height of the ingot.

Distribution of Elements across the Ingot.

Fig. 6 shows the horizontal distribution of the segregating elements across the ingot at 27, 55 and 68% of the height of the ingot. The general

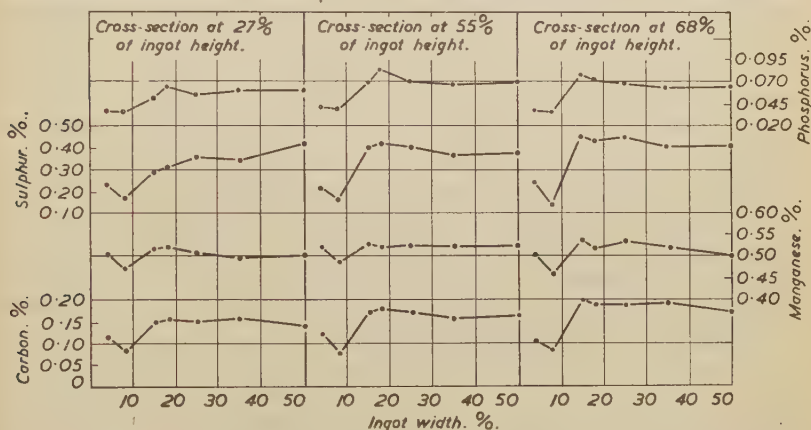


FIG. 6.—Cross-Sectional Distribution of Carbon, Manganese, Sulphur and Phosphorus at 27, 55 and 68% of the ingot height.

pattern of each curve depicts a fall in the rim, a rise at the junction of the core and the rim, and a more or less straight line across the core. From the junction to the core of the ingot there is a distinct tendency for all the elements to decrease. The curves also indicate that the degree of variation across the width of the ingot increases from the bottom to the top of the ingot. On the outside of the rim, the carbon is above the ladle figure and considerably higher than the rim analysis, the actual excess depending upon the position of the cross-section in the ingot. At the bottom and the

middle of the ingot the carbon in the outside of the rim is practically the same as the ladle figure, whereas in the top cross-section it is about 90% of the ladle analysis. The carbon variation in the inner part of the rim is 25–32% below the ladle carbon content. The degree of segregation of this element above the ladle figure varies from 36–73% in the rim-core junction and from 45–63% in the core.

The results of sulphur and phosphorus determinations show that these elements are some 60–80% of the ladle analysis figures in the outer portion of the rim and fall to 45–60% of the ladle figure in the inner portion. At the bottom and the middle of the ingot, the degree of segregation of these elements is practically of the same order. In the bottom cross-section these elements at the junction zone are 7–8% over the ladle figures, whereas in the middle cross-section this variation is of the order of 36–41%. At 68% of the ingot height there is a marked difference in the degree of segregation; whereas phosphorus is 25% in excess of the ladle figure, the sulphur is as high as 56%.

The manganese content of the outer surface of the rim is 11–15% higher than the ladle figure. Although it decreases through the rimmed zone, it does not fall below the ladle analysis, the variation being of the order of 1–7% above the ladle figure. The degree of segregation at the junction and throughout the core varies from 15–17% and 11–15%, respectively, above the ladle determination. This means that there is little difference in the manganese content from the outside to the core.

According to Binnie⁽²⁾ the balanced composition for “nil manganese” is 0.045% of carbon and 0.056% of oxygen. Dickie⁽³⁾ is inclined to think that these values are very nearly correct and that the carbon should be something between 0.040% and 0.045%. However, he does not support Binnie's contention that manganese alters the balanced composition. Thus, there are several points which still require to be carefully examined. In Table I. are assembled, for ready reference, some of the published results on rimming-steel ingots. The probable values given in the third column of the Table were obtained by averaging the available figures of carbon content over the entire ingot, or over one, two or more cross-sections throughout the ingot, as the case may be. The core carbon figures given in the fourth column are an average of the values from inside the junction up to the centre of the ingot. In ingots where analytical figures from the Ingot Committee's standard positions* only were available, carbon determinations from positions *B*, *C*, *D*, *E*, *E'*, and *H* were averaged to express the average core figure. In the fifth column is included the theoretical carbon and oxygen percentages at the balanced composition, calculated according to the expression given by Binnie.⁽²⁾

Reverting to the present example, the theoretical carbon percentage at the balanced composition for the ladle manganese figure of 0.45%, is 0.0714, 0.0875 and 0.101% at 1, 1.5 and 2 atm., respectively. Thus, 0.11% of ladle carbon is above the balanced composition even with a gas-reaction pressure of 2 atm. The average carbon of the entire core is above the ladle analysis figure and is of the order of 0.17%. Further, it appears that the average carbon of the inner part of the rim (see Fig. 2), throughout the whole ingot, could be reckoned at about 0.07%. On this basis the average carbon content of the entire rim zone is found to be about 0.090%; that of the ingot as a whole 0.150%. Actually, this latter figure should normally be below the ladle carbon figure, in view of the concept that the reaction $\text{FeO} + \text{C}$ is mainly responsible for the rimming action and for a decrease in the carbon content of the rim zone. It appears, therefore, that the ladle carbon recorded was very low.

* These positions are shown in Fig. 31 of the Sixth Report on the Heterogeneity of Steel Ingots, p. 64, *The Iron and Steel Institute*, 1935, *Special Report No. 9*.

TABLE I.—Some Published Analytical Data on Rimming-Steel Ingots.

Identification.	Pit Analysis.		Average Carbon of whole Ingot. %.	Average Core Carbon. %.	Balanced Composition for 1, 1.5 and 2 Atm.						Core/Pit Carbon Ratio.
					Carbon, %.			Oxygen, %.			
	Carbon, %.	Manga- nese, %.			1 atm.	1.5 atm.	2 atm.	1 atm.	1.5 atm.	2 atm.	
Present ingot, No. 23606	0.11, 0.11, 0.12	0.45	0.150 (or less)	0.17	0.0714	0.0875	0.1010	0.035	0.0435	0.0495	1.54
Ingot No. 24 ⁽⁴⁾	0.064	0.35	0.078	0.091	0.0654	0.080	0.0924	0.0382	0.0477	0.0540	1.42
Ingot No. 59 ⁽⁶⁾	0.050	0.47	...	0.070	0.0733	0.0897	0.1032	0.0342	0.0417	0.0483	1.40
Ingot No. 61 ⁽⁶⁾	0.080	0.38	...	0.059	0.0673	0.0825	0.0952	0.0374	0.0457	0.0530	0.74
Ingot No. 62 ⁽⁶⁾	0.02	0.028	...	0.031	0.0471	0.0577	0.0666	0.0531	0.0650	0.0750	1.55
Ingot No. 63 ⁽⁷⁾	0.060	0.58	...	0.064	0.0766	0.0935	0.1072	0.0327	0.0400	0.0462	1.07
Ingot No. 64 ⁽⁷⁻¹⁰⁾	0.060	0.54	0.0605 (or less)	0.070	0.0753	0.0922	0.1065	0.0332	0.0407	0.0470	1.17
Ingot No. 65 ⁽⁷⁾	0.050	0.05	...	0.053 (or less)	0.048	0.0587	0.0678	0.052	0.0640	0.0737	1.06
0.16% Carbon-billet ⁽⁸⁾	0.160	0.48	0.162 (or less)	0.185	0.0733	0.0897	0.1032	0.0342	0.0417	0.0483	1.15
Cast 34/8940 ⁽⁹⁾	0.10	0.32	0.076	0.0980 (or high)	0.0635	0.0777	0.0897	0.0395	0.0483	0.0557	0.980
Ingot No. 9368 ⁽¹⁰⁾	0.051	0.065	0.074	0.0824	0.0843	0.1032	0.1195	0.0298	0.0365	0.0421	1.61
Ingot No. 9369 ⁽¹⁰⁾	0.047	0.45	0.041	0.0447	0.0714	0.0875	0.1010	0.035	0.0427	0.0495	0.951
4-Ton ingot ⁽¹¹⁾	0.055	0.49	0.061	0.073	0.0733	0.0897	0.1032	0.0342	0.0418	0.0482	1.33
3-Ton ingot ⁽¹¹⁾			0.063	0.076							
2-Ton ingot ⁽¹¹⁾			0.064	0.075							
1-Ton ingot ⁽¹¹⁾	0.080	0.30	0.065	0.070	0.0622	0.0765	0.0870	0.0409	0.0500	0.0580	0.562
Binnies' ingot ⁽³⁾			0.038	0.045							
Ingot No. 6 (Cast H 3906) ⁽¹²⁾			0.031	0.037							
Nead and Washburn ⁽¹³⁾	0.097	0.40	...	0.064	0.0514	0.0630	0.0727	0.0485	0.0592	0.0685	0.787
Halley and Washburn ⁽¹⁴⁾	0.090	0.40	0.070	0.077	0.0695	0.0850	0.0980	0.0360	0.0440	0.0508	0.855
Hayes and Chipman ⁽¹⁵⁾	0.087	0.41	0.059	0.078	0.0694	0.0850	0.0980	0.0360	0.0440	0.0508	0.896

Acknowledgments.

The authors desire to express their thanks to the Directors of the Tata Iron and Steel Co., Ltd., for the permission granted to publish the results of the investigation.

REFERENCES.

- (1) HULTGREN and PHRAGMÉN : *Jernkontorets Annaler*, 1938, vol. 122, No. 8, p. 377. *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1939, *Iron and Steel Division*, vol. 135, p. 133.
- (2) BINNIE : *Journal of The Iron and Steel Institute*, 1942, No. II., p. 283 p.
- (3) DICKIE : *Journal of The Iron and Steel Institute*, 1942, No. II., p. 366 p.
- (4) Second Report on the Heterogeneity of Steel Ingots, *Journal of The Iron and Steel Institute*, 1928, No. I., p. 480.
- (5) Fourth Report on the Heterogeneity of Steel Ingots, p. 32, *The Iron and Steel Institute*, 1932, *Special Report No. 2*.
- (6) Fifth Report on the Heterogeneity of Steel Ingots, pp. 30, 38, *The Iron and Steel Institute*, 1933, *Special Report No. 4*.
- (7) Sixth Report on the Heterogeneity of Steel Ingots, p. 22, *The Iron and Steel Institute*, 1935, *Special Report No. 9*.
- (8) SWINDEN : Seventh Report on the Heterogeneity of Steel Ingots, p. 15, *The Iron and Steel Institute*, 1937, *Special Report No. 16*.
- (9) SWINDEN : Ninth Report on the Heterogeneity of Steel Ingots, p. 17, *The Iron and Steel Institute*, 1939, *Special Report No. 27*.
- (10) MITCHELL : *Journal of The Iron and Steel Institute*, 1942, No. II., p. 295 p.
- (11) MITCHELL : *Journal of The Iron and Steel Institute*, 1942, No. II., p. 327 p.
- (12) SWINDEN : *Journal of The Iron and Steel Institute*, 1942, No. II., p. 345 p.
- (13) NEAD and WASHBURN : *Metals and Alloys*, 1934, vol. 5, Mar., p. 43.
- (14) HALLEY and WASHBURN : *American Institute of Mining and Metallurgical Engineers*, 1938, *Iron and Steel Division*, vol. 131, p. 195.
- (15) HAYES and CHIPMAN : *American Institute of Mining and Metallurgical Engineers*, 1939, *Iron and Steel Division*, vol. 135, p. 85.

CORRESPONDENCE.

Dr. D. BINNIE (Lancashire Steel Corporation, Ltd., Irlam, near Manchester) wrote : I should like to thank the authors for their very interesting and deductive paper on a rimming-steel ingot. The pit carbons of their ingot do seem to be rather low, and from a rough estimation I would say the figure should be 0.13% of carbon, or at the most 0.14%.

A rim depth of 16% round the ingot gives a volume ratio of rim to core of 1.40, and with a core average of 0.17% of carbon and a rim average of 0.08% of carbon the average analysis of the ingot comes out at about 0.12% of carbon. Owing to carbon loss on rimming, the pit carbon, as the authors say, will be higher than this, say, by 0.01% or at the most 0.02%, giving an estimated pit analysis of 0.14% of carbon.

As the authors have shown in columns 1 and 3 of Table I., the average carbon of published ingots is sometimes higher than the reputed pit carbon, but the live or unskilled pit sample has apparently been sometimes taken to represent the steel, and this pit carbon would certainly be lower than the ladle analysis.

I presume that, in arriving at the average carbon contents of ingots, the authors have integrated the carbon figure relative to its ingot position and not simply averaged the available figures of carbon content over the entire ingot.

For theoretical work on the distribution of carbon in the core of the ingot, or on segregation in rimming steel generally, the ladle carbon must be known as accurately as possible, and the authors have done well in drawing attention to this fact.

The ingots submitted by the authors certainly suggest confirmation of the effect of manganese on the balanced composition, and, for a man-

ganese content of 0.45%, together with a carbon content of about 0.12% or over in the ladle analysis, would mean that no horizontal layer of the core will be lower in carbon than the pit figure.

The authors have found two peaks at the rim-core junction for manganese and sulphur at ingot heights of 46% and 75%. Are not these peaks due to the fact that the rim-core junction is far from homogeneous and that it is easy to drill in an area poorer or richer than the usual run? Would the explanation of these peaks at 46% and 75% of the ingot height not be due to the analysis at ingot height 62% having been lower in manganese and sulphur than might have been anticipated? Sulphur prints of published ingots all show the rim-core junction at the upper part of the ingot to be comparatively free from dark segregates, *i.e.*, there is a falling off but not a complete removal of segregated spots in the rim-core junction.

AUTHORS' REPLY.

The AUTHORS wrote in reply: We wish to thank Dr. Binnie for having taken part in the discussion. Regarding the average carbon contents of ingots, the figures given in Table I. were simply averaged from the available values of carbon content over the entire ingot, obviously not a correct method of computation. The approximate integrated carbon figures are given in Table A. It will be seen that, although these figures are lower,

TABLE A.—Integrated Carbon Contents of Ingots.

Identification Mark.	Pit Sample Carbon, %.	Average Carbon of Whole Ingot, %.	Integrated Carbon of Whole Ingot, %.
Present ingot No. 23606	0.11, 0.11, 0.12	0.15	0.121
Ingot No. 24	0.064	0.078	0.069
Ingot No. 64	0.060	0.0605	0.0565
Cast 34/8940	0.10	0.076	0.070
Ingot No. 9368	0.051	0.074	0.065
Ingot No. 9369	0.047	0.041	0.0404
4-ton ingot	0.055	0.061	0.058
3-ton ingot		0.063	0.059
2-ton ingot		0.064	0.059
1-ton ingot		0.065	0.062
Binnie's ingot	0.080	0.038	0.035
Ingot No. 6 (cast H 3906)	0.047	0.031	0.029
Halley and Washburn	0.090	...	0.070
Hayes and Chipman	0.087	...	0.059

as they ought to be, than the simple average values, they are in some instances higher than the pit-carbon value. This fact emphasizes the importance, as indicated by Dr. Binnie, of properly killing the pit sample in order that it may be representative of the ladle metal.

Regarding the two peaks at the rim-core junction for manganese and sulphur at ingot heights of 46% and 75% we have no explanation to offer other than Dr. Binnie's observations, which appear quite plausible.

THE MANUFACTURE OF SOME THIN-WALLED STEEL CASTINGS, WITH NOTES ON THE INFLUENCE OF POURING SPEED.*

By THE FOUNDRY PRACTICE SUB-COMMITTEE.†

Paper No. 19/1946 of the Steel Castings Research Committee (submitted by the Foundry Practice Sub-Committee).

SYNOPSIS.

Short accounts are given of the moulding and founding procedures used at seven foundries in the production of thin-walled steel castings, and of the influence of the rate of pouring on the quality of the castings produced. With bomb castings least difficulty was met with when the moulds were filled quickly, and also less trouble was encountered with hot steel. There was considerable scabbing with very slow casting or with very cool steel. High rates of pouring also reduced the number of rejections due to hot tears, pulls, and other defects such as sand inclusions. Casting temperatures above 1580° C. gave better results than temperatures below, say, 1550° C. With axle cases satisfactory castings were made over a wide range of pouring speeds, but it should be noted that the casting temperatures are available for only one foundry.

INTRODUCTION.

THE Members of the Foundry Practice Sub-Committee have discussed the influence of the pouring speed on the manufacture of steel castings, and during the discussion it was found that five Members were making the same type of bomb casing (see Section I.) and that two Members were making axle casings (see Section II.); this offered the possibility of comparing the moulding and casting practice in different foundries.

SECTION I.—BOMB CASINGS.

Five reports have been submitted by Members, and the Sub-Committee take this opportunity of expressing their thanks to the Companies concerned for their collaboration in the research.

Firms reporting had made large numbers of bombs, and the conditions necessary to success were fairly well established, so that the incidence of scrap was in all cases low for the type of casting. The uniformity of

TABLE I.—*Steel Analyses, and Pouring Temperatures and Speeds.*

Foundry.	Analysis.					Pouring Temp., °C.	Pouring Speed, sec.
	C, %.	Si, %.	S, %.	P, %.	Mn, %.		
1	0.20-0.28	0.32-0.48	0.014-0.052	0.031-0.064	1.25-1.56	1550-1610	32-51, good 56-58, scabbed 60, scrapped
2	0.23-0.29	0.26-0.41	0.013-0.039	0.045-0.080	1.20-1.54	1450-1550	18-29 (one at 54)
3	0.23	0.25	<0.06	<0.06	1.6	1670-1600 in ladle	20-30
4	0.20-0.29	0.20-0.39	0.018-0.029	0.019-0.028	1.32-1.66	1545-1585	18-22
5	0.26-0.29	0.36-0.43	0.016-0.024	0.019-0.036	1.24-1.39	1410-1490	24-45, one scrapped

* Received May 1, 1945.

† A Sub-Committee of the Steel Castings Research Committee of The Iron and Steel Institute and the British Iron and Steel Research Association.

intentionally poured slowly, considerable scabbing trouble was encountered when they were cast extremely slowly. Similar trouble was encountered with a very cool steel.

Since the foregoing particulars were submitted, further work has been done by one of the Members, and it has been found that with a pouring speed of under 35 sec. the rejections due to the formation of hot tears and pulls are reduced to approximately 2%, and the rejections due to other causes, such as sand inclusions, are also considerably decreased. Similar conclusions have been arrived at with regard to casting temperature, and temperatures in excess of 1580°C . give very much better results than those below, say, 1550°C . In other words, within practicable limits, steel at a temperature that would certainly be dangerous in chilled ingots and some heavier castings does not pull under the conditions of the experiments—a result that was certainly not anticipated by most Members.

Foundry No. 1.

The moulds for the castings in this investigation were machine-moulded, using boxes as illustrated in Fig. 1; details of the runners, &c., are shown in Fig. 2.

The internal cores were hand-made and were finally given a coating of silica paint (see Fig. 3).

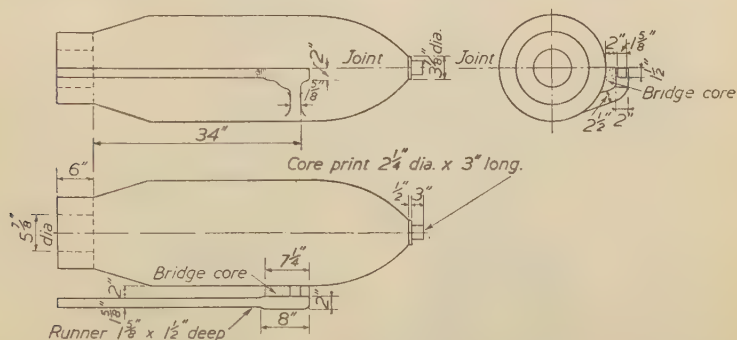


FIG. 2.—Foundry No. 1. Thin-walled steel castings moulded horizontally and cast vertically.

The moulds were filled with steel from a bottom-pour ladle, fitted with a $1\frac{1}{2}$ -in. fireclay nozzle and a graphite stopper end. The ladle contained 43–44 cwt. of liquid steel.

Details of casting temperatures and pouring speeds are given in Table II.

A study of the castings showed that generally they were more free from hot tears and pulls when cast quickly. Slight variations in casting temperature appeared to have little, if any, effect.

Since the foregoing data were obtained, further work has demonstrated the advantages resulting from a higher rate of pour and a higher casting temperature. Pouring times of 35 sec. and under gave extremely good results with very low losses due to rejections resulting from hot tears. Pouring temperatures in excess of 1580°C ., through their effect upon the fluidity of the steel, gave cleaner castings.

Foundry No. 2.

Casting temperatures, pouring speeds, time intervals between the pouring of the moulds, analyses, and mechanical properties of the casts are recorded in Table III. The temperatures were measured with Foster's disappearing-filament optical pyrometer.

TABLE II.—*Casting Details, &c., for Foundry No. 1.*

Date.	Cast No.	Stream Temp., ° C.		Pouring Speed, sec.	C, %.	Si, %.	S, %.	P, %.	Mn, %.	Condition of Castings.
		Immer- sion.	Opti- cal.							
14/2/44	975	...	1440-50	44	0.25	0.35	0.042	0.054	1.46	Good.
		...	1450	38						
		...	1460	42						
		...	1465	37						
		...	1460	38						
		...	1460	38						
16/2/44	993	...	1450	39	0.28	0.48	0.033	0.054	1.54	Misrun.
		...	1440	38						
		...	1455	...						
		...	1460	36						
		...	1465	48						
		...	1465	41						
17/2/44	10	...	1460	47	0.24	0.36	0.014	0.031	1.40	Good.
		...	1445	32						
		...	...	51					
		...	...	47					
		...	...	42					
		...	...	49					
		1620-25?	...	46						Scrapped
		...	...	43					
		...	...	48					
18/2/44	22	...	1445	37						
		...	1455	42						
		...	1460	44						
		...	1455	60						Good.
		1575	1455	44						
		...	1455	34						
		...	1455	39						
1/3/44	135	...	...	43½	0.25	0.39	0.028	0.040	1.42
		44						Scrapped.
		...	...	38					
		...	...	47					
		1562	...	49						
		...	...	43					
		34						Good.
6/3/44	188	...	1430	38	0.27	0.32	0.041	0.039	1.54	
		...	1440	32						
		...	1450	39						
		...	1450	...						
		1535-50	1445	...						
		...	1440	...						Good.
		...	1435	...						
7/3/44	197	...	1460	52	0.26	0.40	0.036	0.040	1.56	
		...	1470	43						
		...	1480	44						
		1595-90	1480	47						
		...	1475	46						Good.
		...	1475	41						
		...	1475	44						
16/3/44	297	...	1465	54	0.20	0.39	0.052	0.064	1.25	
		...	1470	44						
		1575-80	1480	51						
		...	1485	46						Good, stripped well, no scabbing.
		...	1485	45						
		...	1480	56						
		...	1470	57						
		...	1455	44						
		...	1440	46	0.20	0.33	0.018	0.039	1.33	
16/3/44	302	...	1455	53						Scrapped.
		...	1460	50						
		...	1460	31						
		...	1460	42						
		1505?	1455	67						
		...	1440	62						Good, stripped well, no scabbing.
20/3/44	340	...	1430	58	0.24	0.34	0.045	0.056	1.40	
		...	1440	61						
		...	1450	31						
		1515?	1450	56						
		...	1450	58						
		...	1445	57						Intentionally poured slowly and at low temp., 5 good castings, 1 pulled, all scabbed.

TABLE II.—(Continued.)

Date.	Cast No.	Stream Temp., °C.		Pouring Speed, sec.	C, %.	Si, %.	S, %.	P, %.	Mn, %.	Condition of Castings.
		Immer-sion.	Opti-cal.							
21/3/44	348	...	1440	36	0.24	0.39	0.010	0.040	1.53	Very good strip, no pulls.
		...	1450	45						
		...	1465	44						
		...	1465	50						
		1550	1455	54						
27/3/44	412	...	1445	54	0.24	0.37	0.055	0.045	1.50	Very slight scab on nose.
		...	1450	36						
		...	1460	30						
		...	1465	31						
		...	1460	32						
		1560	1460	37						
		...	1455	34						
		...	1445	30						
28/3/44	418	...	1450	38	0.26	0.37	0.018	0.048	1.66	Very good strip, no pulls, slight scabbing on nose.
		...	1460	37						
		...	1465	35						
		...	1460	37						
		1550	1460	32						
		...	1460	36						
		...	1460	36						

Foundry No. 3.

The average analysis of the metal was as follows :

C, %.	Si, %.	S and P, %.	Mn, %.
0.23	0.25	Below 0.06	1.6

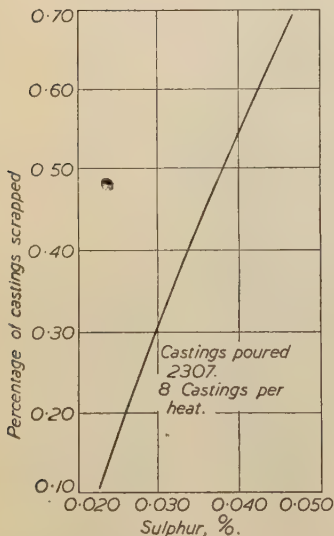


FIG. 4.—Foundry No. 3. Effect of sulphur content on hot tears in thin-walled steel castings.

The sulphur varied somewhat, and the effect of this on the extent of hot tears experienced is shown in Fig. 4.

The steelmaking processes used were (a) Tropenas with desulphurization (by soda ash) and (b) basic electric.

The temperature of the steel in the ladle was 1570–1600° C.

The castings were usually cast four moulds to a heat, there being two castings in each mould cast from a common runner. The pouring time for each pair varied from 20 to 30 sec. as the bucket moved from the first mould to the last. The bucket employed was of the bottom-pour type with a 1½-in. nozzle.

A drawing showing the construction of the mould is given in Fig. 5. The mould was made in three parts, this being done to enable each part to be jolted on the Osborn 905 roll-over and pattern draw, the draw being limited to 20 in.

The following are the details of the sand mix used for the moulds :

- 4 parts of South Cave sand.
- 12 parts of Leighton Buzzard 4.4 sand.
- 4% of Fulbond No. 3.
- 5–6% of water.

TABLE III.—*Casting Details, &c., for Foundry No. 2.*

Date.	Cast No.	Casting No.	Casting Temp., ° C. *	Pouring Speed, sec.	Interval between Pouring Moulds, sec.	Steel Analysis.					Tensile Strength, tons per sq. in.	Elongation, %.
						C, %.	Si, %.	S, %.	P, %.	Mn, %.		
13/4/44	E784	2	1500	26	15	0.26	0.364	0.015	0.049	1.28	37.2	25
		4	1485	26	15							
	E786	6	1510	27	16	0.25	0.392	0.014	0.049	1.33	36.4	28
		8	1490	28	15							
	Double heat {	D577	10	1500	26	0.29	0.410	0.039	0.039	1.54		
		12	1485	25	15							
		E787	14	1475	27							
		16	1470	26	16							
14/4/44	E788	18	1520	22	17	0.23	0.373	0.022	0.059	1.35		
		20	1510	23	16							
	D579	22	1530	23	18	0.23	0.392	0.027	0.055	1.34		
		24	1520	22	17							
	E789	26	1510	25	18	0.23	0.392	0.018	0.056	1.38	39.6	25
		28	1530	26	17							
		30	1515	24	16							
	D581	32	1500	21	15	0.24	0.336	0.026	0.054	1.34		
		34	1500	25	15							
		36	1485	26	14							
		38	1470	26	16							
17/4/44	E792	40	1510	25	12	0.25	0.364	0.022	0.080	1.42	39.6	25
		42	1500	26	12							
	D583	44	1485	28	14	0.24	0.410	0.024	0.068	1.45		
		46	1545	18	15	0.23	0.373	0.022	0.064	1.35	36.8	29
		48	1540	23	12							
	E795	50	1535	23	15							
		52	1520	26	17							
		54	1510	27	16	0.23	0.364	0.044	0.052	1.43		
		56	1520	22	12							
		58	1500	19	12							
		60	1490	19	12							
		62	1485	23	13							
		64	1475	24	19							
		66	1465	28	16							
		68	1460	31	16							
		70	1450	36	...							
18/4/44	D587	72	1450	20	16	0.24	0.287	0.020	0.053	1.38		
	E796	Running stopper										
		74	1490	21	17	0.24	0.345	0.017	0.050	1.38	41.6	25
		76	1475	20	15							
	E797	78	1470	29	19	0.24	0.296	0.013	0.045	1.33		
		80	1550	19	11							
		82	1540	18	12							
		84	1535	54	11							
	E798	Stopper-end off										
		86	1480	23	12	0.26	0.315	0.020	0.048	1.42		
		88	1470	17	12							
		90	1460	23	14							
	E799	92	1530	22	12	0.25	0.305	0.017	0.056	1.37		
	E800	94	1520	21	11	0.25	0.261	0.029	0.055	1.33		
		96	1500	22	13							
19/4/44	E801	98	1510	23	12	0.23	0.354	0.015	0.065	1.28		
		100	1495	24	14							

* Uncorrected.

The moulds were painted while green with silica paint and dried at 300° C. for 11 hr. The moulds dried during the day were dried at 300° C. for only 7 hr., but this did not appear to have any serious effect on the strip, &c. The extra drying given when possible provided an additional safeguard.

The cores (Fig. 6) were made in one part on a 2½-in. dia. barrel wound with wood-wool to leave a 1½-in. wall of sand. The core barrel was placed

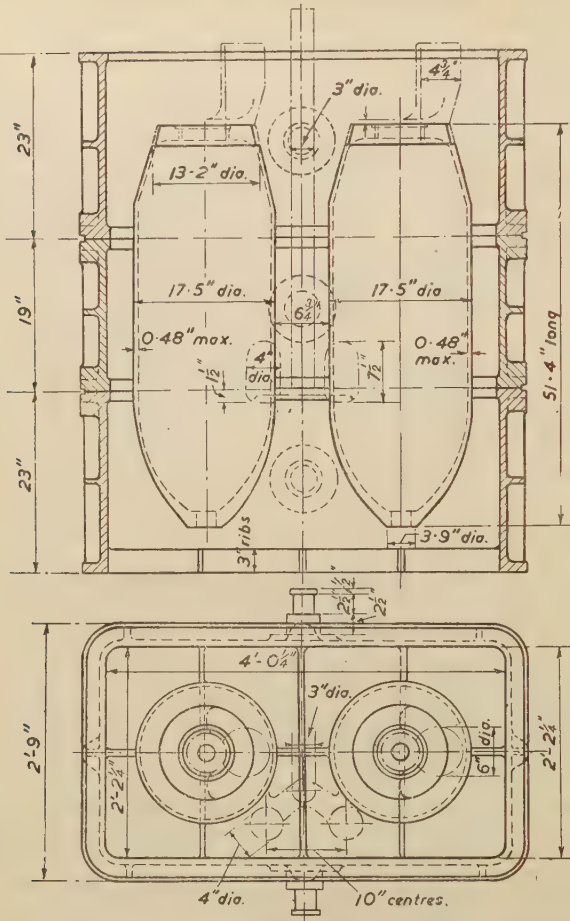


FIG. 5.—Foundry No. 3. Thin-walled steel castings and moulding boxes.

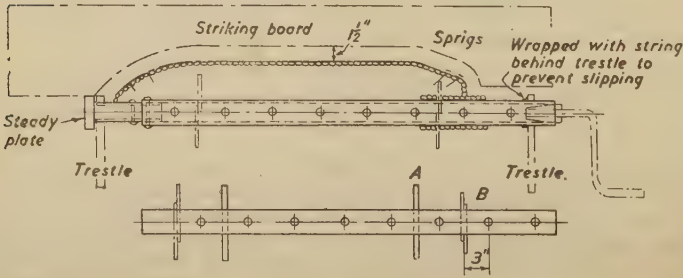


FIG. 6.—Foundry No. 3. Core-making for thin-walled steel castings.

on two trestles and a handle wedged in. The holes in the core barrel had long wooden pegs, $\frac{11}{16}$ in. square by 10 in. long, knocked through, except two holes at each end in which core irons, 8 in. long, were fixed to project 5 in. above the barrel; these were wedged in with horseshoe nails, and then bent over to prevent lifting. Wrapping with straw band commenced at *A* (Fig. 6), and reached to *B*, 3 in. past the last peg, and was held in position with a moulder's sprig, the straw band being well hammered during wrapping. Wrapping then commenced at *A* and was continued to the left and then to the right, being hammered all the time until approximately $1\frac{1}{2}$ in. of space was left between the straw wrapping and the striking board. The rounded ends were prevented from slipping down by driving in at an angle and bending over four or five moulder's sprigs, 6 in. long, at each end. The whole was then bound tightly on the outside with 16-gauge wire. The core was then ready for the moulder.

The following sand mix was used for the cores :

$1\frac{1}{2}$ parts of Yorkshire sand.
 $3\frac{1}{2}$ parts of Chelford sand.
 2% of G.K. Cordek.
 1% of Permol oil.
 $4\frac{1}{2}$ % of water.

The cores were dried at 180–200° C. for 2 hr. and then painted, while still hot, with silica paint. As this was little more than a skin-drying process, the endeavour was made to use the cores within 12 hr. or less of the completion of drying.

Results of air-pressure tests at 30 lb./sq. in. showed that continual attention to the smaller moulding details, in particular the painting of the down runner with an ordinary flue brush, resulted in the leaks in the castings being reduced to 20% of what they had been at the commencement.

Foundry No. 4.

Details of three steel casts, made from a 10-ton Héroult basic electric furnace, which included thin-walled castings, are given below.

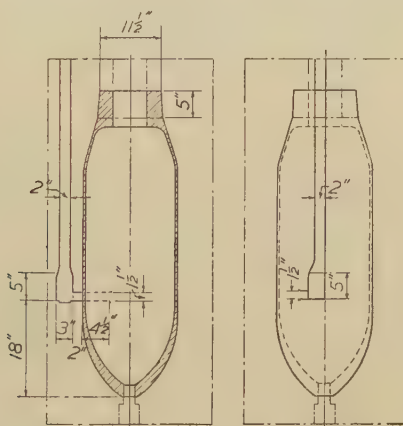


FIG. 7.—Foundry No. 4. Method of casting thin-walled steel castings.

Fig. 7 is a sketch giving particulars of the moulding procedure and core-making. The moulds were made in halves with the horizontal joint

lengthwise on a 4000-lb. roll-over machine; they were dried at 300° C. for 9 hr. and painted with silica paint. The cores were made vertically, using a spindle and wood-wool in a vertical core box split vertically with three horizontal joints to facilitate ramming; they were dried at 200° C. for 7 hr. and painted with silica paint.

The analyses required in each case were as follows :

C, %.	Si, %.	S, %.	P, %.	Mn, %.
0.24-0.27	0.15-0.30	0.030	0.030	1.3-1.5

The heat-treatment applied consisted of normalizing at 950° C. for 6 hr., tempering at 650° C. for 6 hr., and cooling in air.

Casting details are given in Table IV.

TABLE IV.—*Foundry No. 4. Casting Details.*

Heat No.	No. of Castings.	Coupling Box.	Cradles.	Total Weight.	Average Pouring Time per Casting, sec.
2561C	16	...	4	9 tons 12 cwt.	15
2548C	13	...	5	9 " 1 "	15-20
2545C	16	1	2	9 " 2 "	15-17

The analyses of the heats, mechanical test results, and pyrometer readings are given in Table V. The bath temperature varied from 1595° down

TABLE V.—*Foundry No. 4. Three Steel Casts from 10-Ton Héroult Basic Electric Furnace.*

Heat No.	Analysis.					Mechanical Tests.				Temperatures.		
	C, %.	Si, %.	S, %.	P, %.	Mn, %	Max. Stress, tons/ sq. in.	Yield Point, tons/ sq. in.	Elongation on 2 in., %.	Bend.	Sample.	Leeds and Northrup Optical Pyrometer, ° O.	Tinsley Immersion Pyrometer, ° O.
2561C	0.24	0.14	0.021	0.020	1.42	36.6	26.0	27	120*	Spoon sample	1650	...
										Bath	...	1595
										Spoon sample	1610	...
										Start of stream	...	...
										from furnace	1623	...
										End of stream	1660	...
										First casting	1585	...
										Last casting	1566	...
2548C	0.24	0.20	0.029	0.028	1.46	35.6	26.0	26	120*	Spoon sample	1600- 1610	...
										Bath	...	1575
										Stream from	1610-	...
										furnace spout	1630	...
										First casting	1585	...
										Last casting	1550	...
2545C	0.25	0.20	0.029	0.027	1.53	36.0	24.0	28	120*	Spoon sample	1570	...
										Bath	...	1555
										Stream from	1600-	1560
										furnace spout	1620	...
										First casting	1570	...
										Last casting	1545	...

* Unbroken.

to 1555–1560° C. The lower temperature was governed by the fact that after casting the 16 thin-walled castings heavier castings had to be poured, but it has been found that 1590–1560° C. is the range within which no difficulty in running-up is met with.

Details of 102 thin-walled steel castings are given in Table VI. None of the castings was pulled, but three were scrapped, two for a short run and one for a burst core.

TABLE VI.—*Foundry No. 4. Details of 102 Thin-Walled Steel Castings.*

Bath temperature taken with Tinsley immersion pyrometer. Ladle nozzle $1\frac{1}{2}$ in. in dia.

Date.	Heat No.	Number Cast.	Analysis.						Casting Temp., ° C.	Average Casting Time per Casting, sec.
			C, %.	Si, %.	S, %.	P, %.	Mn, %.	Ni, %.		
1/5/44	C2665	10	0.20	0.20	0.023	0.024	1.50	0.50	1560	20
2/5/44	C2669	12	0.23	0.29	0.022	0.023	1.50	0.52	1565	18
3/5/44	C2671	15	0.23	0.39	0.020	0.026	1.45	0.40	1560	20
6/5/44	C2678	12	0.27	0.39	0.018	0.020	1.54	0.43	1560	20
11/5/44	C2688	15	0.23	0.24	0.032	0.026	1.66	0.24	1570	18
12/5/44	C2691	14	0.23	0.21	0.033	0.025	1.44	0.35	1565	20
16/5/44	C2698	12	0.29	0.29	0.019	0.019	1.32	0.37	1580	22
17/5/44	C2701	12	0.22	0.26	0.023	0.019	1.35	0.35	1565	20

Foundry No. 5.

The steel used was basic electric from 10-ton Birlec-Lectromelt furnaces.

The castings were moulded two in a box and run from a single down-runner, the general arrangement being as shown in Fig. 8.

Apparent temperatures were measured by a Cambridge disappearing-filament pyrometer.

The analyses of six heats and casting data are given in Table VII.

The teeming times generally indicate slower pouring of the initial boxes owing to cold nozzles. There was, as a result, some hesitancy in opening up.

The total number of castings poured was 124; the number scrapped was 7, or 5.65%. Of those scrapped, one casting had a bad hot tear, while the remainder were scrapped owing to foundry faults which could not in any way be attributed to variables in teeming practice.

SECTION II.—HEAVY AUTOMOBILE REAR-AXLE CASES.

It was found that two Members of the Foundry Practice Sub-Committee were making heavy automobile rear-axle cases and it was considered that the rate of pour might be critical in this type of casting.

The finished weight of the casting was 182–190 lb. and the castings were required to be identical and interchangeable dimensionally; it was therefore considered that for the purposes of the comparison in mind the castings would be ideal.

The general dimensions of the castings are shown in Fig. 9, and the moulding practice employed in the two foundries is indicated in Table VIII.

The pouring speeds were controlled by means of a choke core, which was incorporated in the runner system, as detailed in Fig. 10.

Details of the mould hardness, choke diameters, cross-sectional areas of the chokes and pouring times are recorded in Table IX.

Optical-pyrometer readings are available only for Foundry No. 6, and these are also given in Table IX.

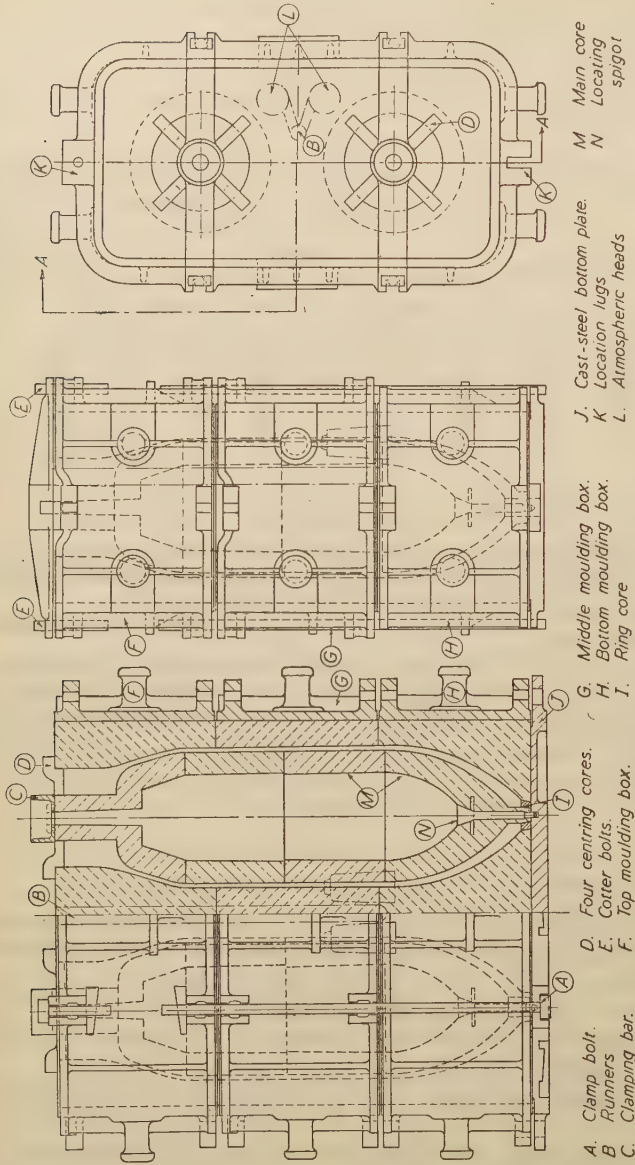


Fig. 8.—Foundry No. 5. General arrangement of cast-iron moulding boxes for thin-walled steel castings and general assembly.

TABLE VII.—*Foundry No. 5. Analyses and Casting Data.*

Heat No. : Date :	4632. 19/1/44.	4633. 19/1/44.	4635. 20/1/44.	4638. 21/1/44.	S707. 22/1/44.	S718. 27/1/44.
Analysis : C, %	0.26	0.27	0.29	0.26	0.26	0.27
Si, %	0.38	0.42	0.36	0.43	0.38	0.42
S, %	0.019	0.016	0.023	0.024	0.024	0.020
P, %	0.036	0.030	0.026	0.022	0.019	0.024
Mn, %	1.35	1.39	1.24	1.32	1.25	1.34
Temp. in furnace immediately before tapping (immersion), °C.	1608	1616	1568	1595	1596	1560
Apparent temp. in launder, °C.	1500	1500	1480	1490	1500	1440
Weight of steel in ladle	7 tons 10 cwt. 2	7 tons 10 cwt. 2	7 tons 10 cwt. 2	9 tons 10 cwt. 2	7 tons 10 cwt. 2	7 tons 10 cwt. 2
Nozzle size, in.						
Teeming of castings :						
1	Apparent Temp., °C. 1460	Apparent Temp., °C. 1490	Apparent Temp., °C. 1470	Apparent Temp., °C. 1460	Apparent Temp., °C. 1460	Apparent Temp., °C. 1410
2	Time, sec. 33	Time, sec. 40	Time, sec. 38	Time, sec. 40	Time, sec. 45	Time, sec. 35
3	39	33	32	25	30	37
4	35	25	25	30	36	32
5	32	30	31	22	30	27
6	33	32	30	25	28	24
7	30	28	28	25	30	36
8	32	32	25	28	26	40
9	30	35	30	28	32	38
10	32	33	...	22	29	40
11	32	36	...	30	30	...
12	...	...	...	30	...	...
13	...	...	...	30	...	...
14	...	...	...	30	...	...
Remarks	2 scrapped, foundry faults.			1 scrapped, hot tear; 4 scrapped, foundry faults.		

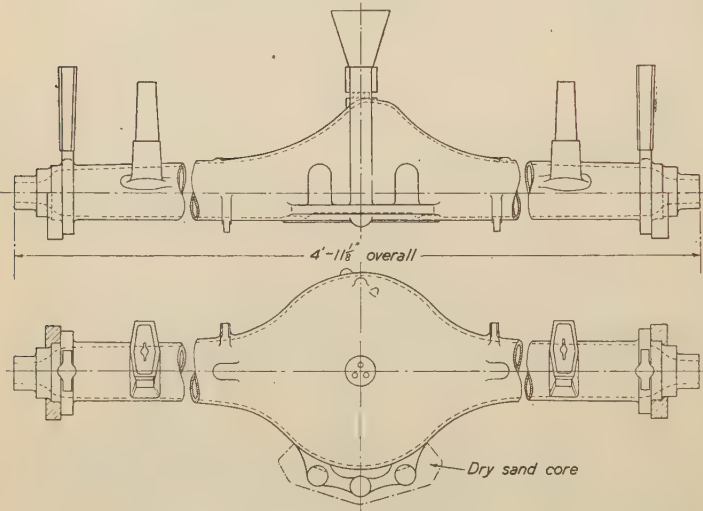
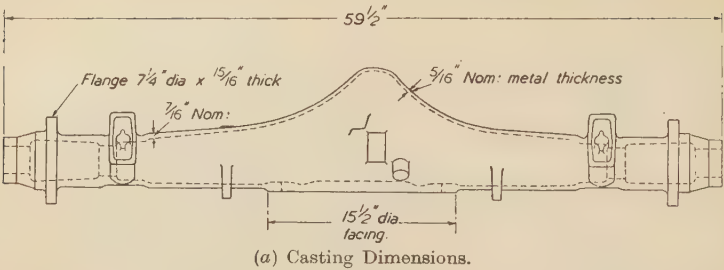


FIG. 9.—Details of the Automobile Rear-Axle Casings.

TABLE VIII.—Automobile Rear-Axle Casings. Foundry Data.

	Foundry No. 6.	Foundry No. 7.
Moulds	Green sand.	Green sand.
Sand properties	Facing sand.	Facing sand.
Moisture, %	3.5	3.2
Green strength, lb./sq. in.	7.5	8.5
Green permeability	300	155
Cores	Green sand. (Lower half of arm cores, oil sand.)	Green sand. (Lower half of arm cores, oil sand.)
Yield :		
Weight of casting, lb.	182	190
Metal poured, lb.	236	240
Yield, %	77.1	79.2
Moulding methods	Sand slinger.	Jolt machine.
Nozzle dia., in.	1 1/2	1 1/2

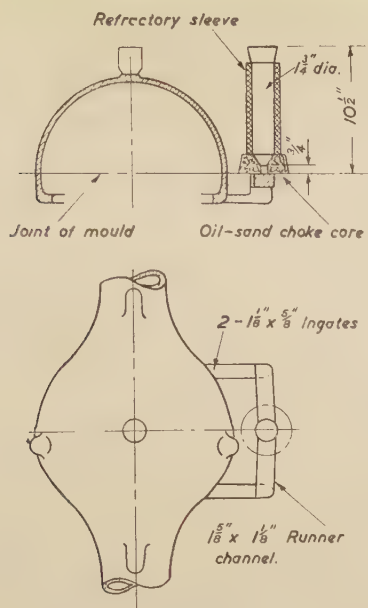


FIG. 10.—Details of the Down-Runner and Special Oil-Bonded Sand-Choke Core.

TABLE IX.—*Automobile Rear-Axle Casings. Mould Data and Pouring Times and Temperatures.*

Casting No.:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
<i>Foundry No. 6.</i>											
Mould hardness .	86	90	91	93	88	88	94	93	89	91	93
Diertert No. .	90	90	85	89	85	82	87	86	89	90	86
Choke dia., in. .	$\frac{9}{16}$	$\frac{11}{16}$	$\frac{13}{16}$	1	$1\frac{1}{8}$	$1\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{1}{8}$	1	$\frac{7}{8}$	$\frac{1}{2}$
Choke area, sq. in. .	0.25	0.37	0.52	0.79	2.4	2.1	1.8	0.99	0.79	0.60	0.20
Casting time, sec.	38	27	22	15	13	18	21	21	21	20	41
Casting stream temp., optical, ° C. .	1575	1575	1575	1575	1570	1570	1555	1555	1555	1550	1545
<i>Foundry No. 7.</i>											
Mould hardness .	87	80	90	85	82	85	82	87	80	85	85
Diertert No. .	70	73	75	79	73	73	70	79	73	80	75
Choke dia., in. .	$\frac{9}{16}$	$\frac{11}{16}$	$\frac{13}{16}$	1	$1\frac{1}{8}$	$1\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{1}{8}$	1	$\frac{7}{8}$	$\frac{1}{2}$
Choke area, sq. in. .	0.25	0.37	0.52	0.79	2.4	2.1	1.8	0.99	0.79	0.60	0.20
Casting time, sec.	40	25	23	16	16	15	13	12	14	20	33

The relationships between the running time and pouring rate on the one hand and the diameter and area of the choke on the other are shown in Fig. 11.

The castings were poured from electric steel cast from a bottom-poured ladle; it will be seen from the recorded data that the nozzle method of pouring steel does not lend itself to accurate control, and the pouring

speeds are in the hands more of the ladleman rather than the designer of the runner system.

Foundry No. 6 used a $1\frac{1}{2}$ -in. dia. nozzle, whilst Foundry No. 7 made use of a $1\frac{1}{8}$ -in. dia. nozzle.

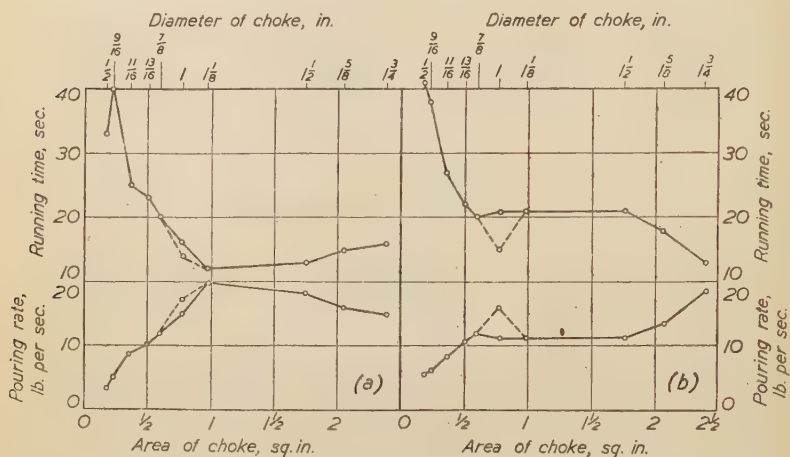


FIG. 11.—Running Time and Pouring Rate Plotted against Diameter and Area of Choke. (a) Foundry No. 7, (b) Foundry No. 6.

In each foundry the pouring rate was fairly constant over a wide range of choke sizes except at the extreme top and bottom of the scale.

In both foundries casting No. 11 was badly short-run, but the remainder, which were fully run-up, were quite acceptable for subsequent service, and it can be stated that with the design selected for the purpose of this test satisfactory castings can be made over a wide range of pouring speeds.

OBITUARY.

Sir WILLIAM HENRY ELLIS, G.B.E., died at the Sheffield Royal Infirmary on July 4, 1945, aged eighty-four. Born in 1860, he was the fourth son of Mr. John Devonshire Ellis, a former Chairman and one of the original partners of Messrs. John Brown and Co., Ltd., of Sheffield and Clydebank. He received his education at Uppingham and served a pupilage at Messrs. Tannett, Walker and Co., a Leeds engineering firm, at the same time continuing his studies at the Yorkshire Technical College, Leeds (which later became Leeds University). On completion of his training, he was put in charge of the erection of a vertical blowing engine at a smelting works in Serbia. Three years later, in 1885, he was engaged on the installation of forging plant at the Atlas Works of Messrs. John Brown and Co., Ltd.; this work being finished, he was engaged by that firm as manager of the forging and machining department, where he remained for fifteen years. In 1903 he became assistant to the Managing Director, Sir Charles Ellis, his elder brother. While holding this position he did much, as a member of the Joint Works Committee, to increase the output of munitions during the first world war. In 1919 he was appointed Managing Director of the Company; he retired from this position in 1928, but continued as Managing Director of the firm's colliery interests, until, in 1931, after forty-three years' service with Messrs. John Brown and Co., Ltd., he finally retired.

Sir William was also a Director of the Sheffield and South Yorkshire Navigation Company, as well as being a member of the General Board of the National Physical Laboratory, and a member of the Privy Council Committee of the Department of Scientific and Industrial Research. He was on the Governing Body of the Imperial College of Science and Technology, and was a member of the Government Commission on Drainage (Doncaster Area), of the Cambridge University Appointments Board and of the Overseas Committee of the Board of Trade. For two years he was Deputy Chairman of the Disposals Board.

He was for some time a Colonel in the Engineering and Railway Staff Corps of the Royal Engineers (T.A.). He was created a Knight Grand Cross of the British Empire in 1918, and shortly afterwards he received the honorary degree of Doctor of Engineering of Sheffield University, of which he was a Member of Council.

He joined The Iron and Steel Institute in 1905, and was elected a Member of Council in 1907, a Vice-President in 1915, and from 1924 to 1925 was President. He became an Honorary Member in 1932. Sir William was also President of the Sheffield Society of Engineers and Metallurgists in 1904, and of the Institution of Civil Engineers from 1925 to 1926. He created a record by holding the position of Master Cutler of Hallamshire for four years in succession during the war of 1914-18.

A talented musician, Sir William was President of the Sheffield Amateur Musical Society in 1918, and of the Sheffield and District Organists' and Choirmasters' Association in 1936. He was also a keen mountaineer and founded the Sir William Ellis Trust for Guides of Swiss Nationality; he was a member of the Swiss Alpine Club. He celebrated his seventieth birthday by climbing the Jungfrau.

He was a well-known figure in the public life of Sheffield, where he became a magistrate in 1915. He was Town Trustee, and for forty-three years was on the Board of the Sheffield Royal Infirmary.

JAMES HENDERSON, J.P., died at Leatherhead on November 20, 1945, at the age of seventy-seven, after an operation. He was born in Glasgow in 1868, and educated at Hutchinson's Grammar School and Allan Glen

Technical College. His first appointment was as a laboratory assistant with the Glasgow Iron and Steel Co., Ltd., at Wishaw. From there he moved, in 1889, to the Frodingham Iron and Steel Co., Ltd., as chief metallurgist. After holding a number of positions in various departments, he became assistant to the Managing Director, Mr. Maximilian Mannaberg, who had come from Gebrüder Stumm, Neunkirchen. When Mr. Mannaberg retired in 1920 Mr. Henderson became Managing Director in his place. Soon afterwards he was elected a Director of The United Steel Companies, Ltd., of Sheffield, which had absorbed the Frodingham Company in 1917. His lifelong connection with the Frodingham Iron and Steel Co. did not end when he, in turn, retired from active management in 1934, as he continued to serve as Deputy-Chairman of the re-named Appleby-Frodingham Steel Co., Ltd.

Mr. Henderson was connected with the Company for over half a century, where he witnessed and was responsible for many major developments and valuable additions during this period. He saw the development of the basic open-hearth process from its early stages and of the Talbot process from its introduction into the works in 1906. Many experiments were made on the utilization of blast-furnace gas and one of the first Cockerill gas-engine-driven generator sets was installed at Frodingham. For many years the application of blast-furnace gas to blowing and power purposes has been a large item of economy at Frodingham. In 1927 the Appleby plate mills were completed and were then the last word in plate-rolling practice in Europe; some ten years later two of the largest blast-furnaces in Europe, together with a most up-to-date ore-bedding plant, were installed.

From 1919 to 1921 Mr. Henderson was Chairman of the Lincolnshire Iron and Steel Institute, and from 1928 to 1935 of the Lincolnshire Ironmasters' Association. He joined the Council of the National Federation of Iron and Steel Manufacturers at its inception in 1918, and was its last President; he took a leading part in its reorganization in 1934 as the British Iron and Steel Federation, and was the first President of the new body. He also presided at the Joint Conference, held in London in December, 1934, on the proposal that Great Britain should join the Entente Internationale d'Acier. He was Chairman of the Furnace Committee of the Iron and Steel Industrial Research Council, and President of the latter from 1934 to 1936, a Member of Council of the Federation of British Industries, and, in 1938, President of the British Steelwork Association. In 1937 he was nominated an Honorary Member of the Verein Deutscher Eisenhüttenleute.

For more than fifty years Mr. Henderson was associated with The Iron and Steel Institute, and his name will always be remembered amongst those who have rendered it invaluable services. Joining the Institute in 1892, he was elected a Member of Council in 1925 and a Vice-President in 1931. In 1936 he served as Acting President at the Autumn Meeting of the Institute held at Düsseldorf. From 1934 to 1942 he held the position of Honorary Treasurer and in that capacity played a large part, under Lord Dudley's Presidency, in arranging for the acquisition of the present offices of the Institute. He was the Institute's representative on the Governing Body of The Imperial College of Science and Technology, on the Advisory Council of the Science Museum, and on the Technical Committee of Lloyd's Register of Shipping. From 1942 to 1944 he served as President; during his Presidency negotiations between The Iron and Steel Institute and The Institute of Metals resulted in a much closer collaboration. A scheme was laid out for the introduction of National Certificates and for the formation of the recently inaugurated Institution of Metallurgists. In 1944 he was elected an Honorary Member. In 1939, in recognition of his great services to the iron and steel industry and to the Institute, he was

awarded the Bessemer Gold Medal. A few months before his death his portrait by Oswald Birley was presented to the Institute by the Board of The United Steel Companies, Ltd.

WILLIAM ROYSE LYSAGHT, C.B.E., D.L., J.P., died at his home at Castleford, Chepstow, on April 27, 1945, at the age of eighty-six. Born in 1858, and educated privately, he was the nephew of Mr. John Lysaght, who founded the world-famous firm of Messrs. John Lysaght, Ltd., at Bristol over a hundred years ago.

When his uncle took over the Swan Garden Works and the Osier Board Works at Wolverhampton in 1878, Mr. Lysaght was made manager of both and later became Chairman and Managing Director of the whole concern; he held this position until his retirement in 1940, when, at the request of his fellow-Directors, he agreed to continue in the less active capacity of President.

Mr. Lysaght held a number of positions outside his own firm; for twenty-five years he was Chairman of the Sheet Trade Committee, and for forty years was a member of the Midland Wages Board. He was also Chairman of Messrs. Joseph Sankey and Sons, Ltd., and a Director of Messrs. Bayliss, Jones and Bayliss, Ltd., of The Broken Hill Proprietary Co., Ltd., of Messrs. Guest Keen and Nettlefolds, Ltd., and of Messrs. John Carrington and Sons, Ltd.

During the sixty-three years for which he was connected with his uncle's firm he was responsible for carrying out many major developments, including the transference of the firm from Wolverhampton to Newport and the opening of new works at Scunthorpe. He played a large part in inaugurating the sheet-mill industry in Australia, and for some time the whole of their steel-sheet requirements have been supplied from the Lysaght works.

Having joined The Iron and Steel Institute in 1888, he was elected a Member of Council in 1915, a Vice-President in 1924, and was President from 1933 to 1935. During his presidency the Institute paid its very successful visit to Belgium and Luxemburg in September, 1934; it was at the meeting in Brussels that he announced that H.M. King Leopold had consented to become an Honorary Member of the Institute.

In 1918 he was made a Commander of the Order of the British Empire in recognition of the great services that he had rendered to the country during the first world war by his work at the Ministry of Munitions.

Throughout the whole of his career Mr. Lysaght made a point of studying the men who worked under him, and it was always his aim to know as many of them as he could personally. As a result, he was looked upon with the utmost trust and confidence; in fact, he was regarded as a father rather than as an employer. In 1928, after he had been with the Company for fifty years, he was the guest of honour at a dinner given by his workmen, who paid him a further tribute a few years ago by erecting the W. R. Lysaght Memorial Institute. The spirit of understanding which existed between him and his men did much to prevent the occurrence of strikes amongst his employees.

Mr. Lysaght's benefactions were innumerable and many are the families who can testify how his generosity has helped them in times of stress.

Outside the iron and steel industry Mr. Lysaght held a number of important offices. During his stay at Wolverhampton he was President of the Chamber of Commerce, and in 1915 he was proclaimed High Sheriff of Monmouthshire, where he was also Deputy Lieutenant and a Justice of the Peace. In 1923 he was elected an underwriter at Lloyd's. In recognition of his services to the town and district of Newport he was made an Honorary Freeman of the County Borough of Newport in 1936. Besides being one of its founders, he was Chairman of the Chepstow Racecourse Company.

CARL ALFRED BENDIX died under tragic circumstances at his home near Northleach, Gloucestershire, where he was found shot on February 7, 1945. A farmer, financier and industrialist, Mr. Bendix had, until 1943, been associated for many years with the stockbroking firm of Messrs. Haes and Sons. His chief interests and greatest achievements were in India, where in 1925 he played a leading part in bringing about the combination of the Bengal Iron Co., Ltd., with the Indian Iron and Steel Co., Ltd.; this resulted in the formation of one of the largest concerns in India. He was Chairman of the London Boards of the India Iron and Steel Co., Ltd., and the Steel Corporation of Bengal, Ltd. Mr. Bendix was made a member of the London Stock Exchange in 1904. He became a Member of The Iron and Steel Institute in 1929.

Major THOMAS GRIFFIN BIRD, D.S.O., died at Newcastle-upon-Tyne on May 7, 1945. He had been with Sir W. G. Armstrong, Whitworth and Co., Ltd., for the last twenty-five years, and latterly was Managing Director of Sir W. G. Armstrong, Whitworth and Co. (Ironfounders), Ltd., and of the Jarvis Industries Group. In 1920 he became a member of the North-East Coast Institution of Engineers and Shipbuilders, and in 1929 a member of the Institute of British Foundrymen. He was elected a Member of The Iron and Steel Institute in 1934.

CHARLES KINGSTON EVERITT died at his home at Grindleford, Derbyshire, on February 6, 1945, at the age of seventy-eight. He was educated at the Royal Grammar School, Sheffield, and in 1882, at the age of fifteen, he joined the works of Messrs. Edgar Allen and Co., Ltd., at the same time continuing his studies at Firth College and Sheffield Technical School. His outstanding ability was soon recognized, and, rising from the positions of assistant steel manager and manager of the steel department, he was made a Director of the Company in 1908 and Chairman in 1930. He was also a Director of several smaller companies. He presented a number of papers on steelmaking to the technical press, and frequently took part in discussions on papers presented to The Iron and Steel Institute. Mr. Everitt was the first President of the Sheffield and District Engineering and Steel Trades Council and a Past-President of the Sheffield Society of Engineers and Metallurgists. He was closely connected with the steel-melting section of the Sheffield Trades and Technical Society.

Some thirty-five years ago he played a large part in introducing the Héroult electric-arc furnace into Britain, and his high-frequency crucible furnace installed at Sheffield was one of the first in the world to produce high-grade tool steels.

When Sir George May introduced his scheme in 1932 for reorganizing the steel industry, Mr. Everitt was elected a member of the Sheffield Regional Sub-Committee. His name was well-known in the steel industries of many countries, and steelmakers from the United States often made use of his outstanding knowledge by seeking his advice.

He became a Member of The Iron and Steel Institute in 1904.

Sir ALLAN CAMPBELL MACDIARMID died in London on August 14, 1945, a few days before his sixty-fifth birthday. Born in Glasgow, he was educated at Kelvinside Academy and Uppingham, and in 1898 joined Messrs. McClelland, Ker and Company, a Glasgow firm of chartered accountants. In 1903 he passed with distinction his final examination as a chartered accountant, and in 1906 took up an appointment as Secretary to Messrs. Stewarts and Lloyds, Ltd. In 1918 he was made a Director of the Company and became Chairman and Managing Director in 1926.

Sir Allan, who received his knighthood in January, 1945, was a leading

figure in the iron and steel industry, and particularly in the steel-tube trade. It was under his chairmanship that the great undertaking at Corby was started and developed into a completely integrated iron and steel plant working with the most modern and economical methods. He was also concerned with the creation of the Entente Internationale d'Acier, and the first International Tube Cartel.

He was Chairman of the Stanton Ironworks Co., Ltd., United Tube Holdings, Ltd., and New Cross Forgings, Ltd., and a Director of Tube Investments, Ltd., The United Steel Companies, Ltd., and Messrs. Richard Thomas and Co., Ltd. He retired from the Board of Messrs. Davy and United Engineering Co., Ltd., and Messrs. Wellman Smith Owen Engineering Corporation, Ltd., when he was appointed President of the British Iron and Steel Federation in 1944. He was mainly responsible for the new constitution recently adopted by this organization, and in his capacity as President he had been engaged in problems of post-war reconstruction in close collaboration with the Board of Trade and other planning departments.

Sir Allan was a Vice-President of the British Employers' Confederation and an Extra-ordinary Director of the Bank of Scotland. He was elected a Member of The Iron and Steel Institute in 1934.

Sir JOHN SCURRAH RANGLES died at his home at Bristowe Hill, Keswick, on February 11, 1945, aged eighty-seven. He was the son of Dr. Marshall Randles, Professor of Theology at Didsbury, Manchester. His career started at Messrs. Joshua Hoyle and Sons, Ltd., Manchester, and it was not until 1891, at the age of thirty-three, that he became associated with the iron and steel industry. He was later made Chairman of the Workington Iron and Steel Co., Ltd., and was largely responsible for amalgamating the West Cumberland iron and steel industry into an efficient self-contained unit. A knighthood was conferred upon him in 1905.

Sir John's career was not confined to industry. From 1912 to 1922 he was Member of Parliament for Manchester (North-West), having previously represented the old Cockermouth Division (which included Workington) for ten years. He took a keen interest in education; he played a large part in the foundation of Workington Technical College and gave £1000 for the endowment of a scholarship in metallurgy. He was a generous benefactor to The National Trust. On his retirement the West Cumberland Combine was taken over by The United Steel Companies, Ltd.

Sir John was elected a Member of The Iron and Steel Institute in 1896, and was a Member of Council from 1915 to 1923.

JOHN ALFRED SMEETON died in London on June 24, 1945, at the age of sixty-nine. He was educated at Levenshulme College, Manchester, and at the Manchester College of Technology. He then started a very extensive practical training by serving an apprenticeship at Messrs. Higginbottom and Mannock, Messrs. Crossley Brothers, and Messrs. Beyer, Peacock and Co., Ltd. After a further training as a fitter at Messrs. Vickers and Sons, and Maxim, Ltd., Barrow-in-Furness, he went to sea for about two years as an assistant engineer with the Peninsular and Oriental Steam Navigation Company. Following this he held the position of engineering representative with the Klein Engineering Co., Ltd., Manchester, for four years, and in 1903 went to Messrs. Arthur Coppel and Company as engineer and manager. Three years later he was appointed London manager to Messrs. Richardsons, Westgarth and Co., Ltd., and held this position until 1909, when he transferred to Fusion Welded Metals, Ltd., as Managing Director, and later to the British Perlit Iron Co., Ltd., in a similar capacity. During the first world war he was London Director of Messrs. Marshall, Sons and Co., Ltd., Gainsborough.

In 1916 Mr. Smeeton formed his own company of John A. Smeeton, Ltd., which specialized in heavy foundry, ironworks, steelworks, and rolling-mill plant. He held the position of Chairman and Managing Director and did a great deal of work as a consulting engineer and engineers' agent. He took over the British agency for Demag and other Continental concerns. He made many contributions to the steel industry and wrote frequently in the technical press; he was responsible for the introduction of the Collin ladle into Britain from Belgium.

Mr. Smeeton was a member of the Institution of Mechanical Engineers, the Institute of British Foundrymen, and The Iron and Steel Institute, which he joined in 1909, and in spite of his many responsibilities he found time to participate actively in all of them.

HENRY HALL SUMMERS died at Harrogate on January 24, 1945, on the eve of his eightieth birthday. He was educated at Malvern College and Owen's College, Manchester (later Manchester University), and then received training in an engineering works. In 1889 he entered his father's business, Messrs. John Summers and Sons, Ltd., Hawarden Bridge Steelworks, Shotton, Chester, of which he later became Chairman and, finally, President. The rapid growth of this concern to its present size and its prominent position in the iron and steel industry to-day are largely due to his initiative and enterprise.

Mr. Summers was especially associated with the sheet-metal trade; he formed the Association of British Sheet Rollers, and was Chairman of the Steel Sheet Conference from its inception in 1905 until his retirement in 1935. He was also Chairman of a number of associated concerns, including the Shelton Iron, Steel and Coal Co., Ltd., the Buckley Colliery Co., Ltd., and the Castle Firebrick Co., Ltd.

He was an Alderman on the Flintshire County Council and an ex-Director of the District Bank, Manchester.

Mr. Summers joined The Iron and Steel Institute in 1919.

EDGAR R. SUTCLIFFE died at Edenbridge, Kent, on May 16, 1945, at the age of seventy. He was the founder and for many years Managing Director of Messrs. Sutcliffe, Speakman and Co., Ltd., a firm of engineers at Leigh, Lancashire. With Mr. E. C. Evans he was the author of a paper on "The Reactivity of Coke as a Factor in the Fuel Economy of the Blast-Furnace" which was presented to the Institute (*Journal*, 1923, No. I.).

Mr. Sutcliffe became a Member of The Iron and Steel Institute in 1920.

JOHN ALFRED EDWARD WELLS, who died at Sheffield on September 9, 1945, at the age of fifty-nine, was the son of Mr. A. E. Wells, at one time Managing Director of Messrs. Edgar Allen & Co., Ltd., Sheffield. Educated at Wellingborough School, Northamptonshire, and at Sheffield Technical School, where he studied engineering and metallurgy, Mr. Wells received his practical training at the Yorkshire Engine Co., Ltd., Sheffield, where he spent three years in the shops and drawing office. In 1907 he joined Messrs. Edgar Allen & Co., Ltd., and was for some time engaged on practical work in the laboratory, in the Tropenas steelmaking plant, and in the foundry, where he worked as a moulder and core-maker, later being put in charge of the core shop. In 1936 he was made foundry manager, and joined the Board a few months later. By his very thorough training and his close association with the men in his early days, Mr. Wells developed a wide practical knowledge and a complete understanding of his men for which he was well-known and much respected.

He was a member of the Institute of British Foundrymen, and became a Member of The Iron and Steel Institute in 1937.

Colonel PENRY WILLIAMS died at Harrogate on June 26, 1945, at the age of seventy-nine. The son of Mr. Edward Williams, one of the pioneers of the Cleveland iron trade, he was educated privately and at Surbiton. He was a volunteer in the Royal Artillery for many years, and joined H.M. Forces as an infantryman when the 1914-18 war broke out. He finally reached the rank of lieutenant-colonel in command of the 2nd/4th Battalion of the Yorkshire Regiment, which he helped to form in Middlesbrough.

Colonel Williams, who had been connected with the Linthorpe Iron Works, Middlesbrough, was Member of Parliament for the Middlesbrough area from 1910 until 1924, and was well known in the North of England for his work in the iron trade and in connection with the National Liberal Federation. •

He was one of the oldest Members of The Iron and Steel Institute, having been elected in 1888.

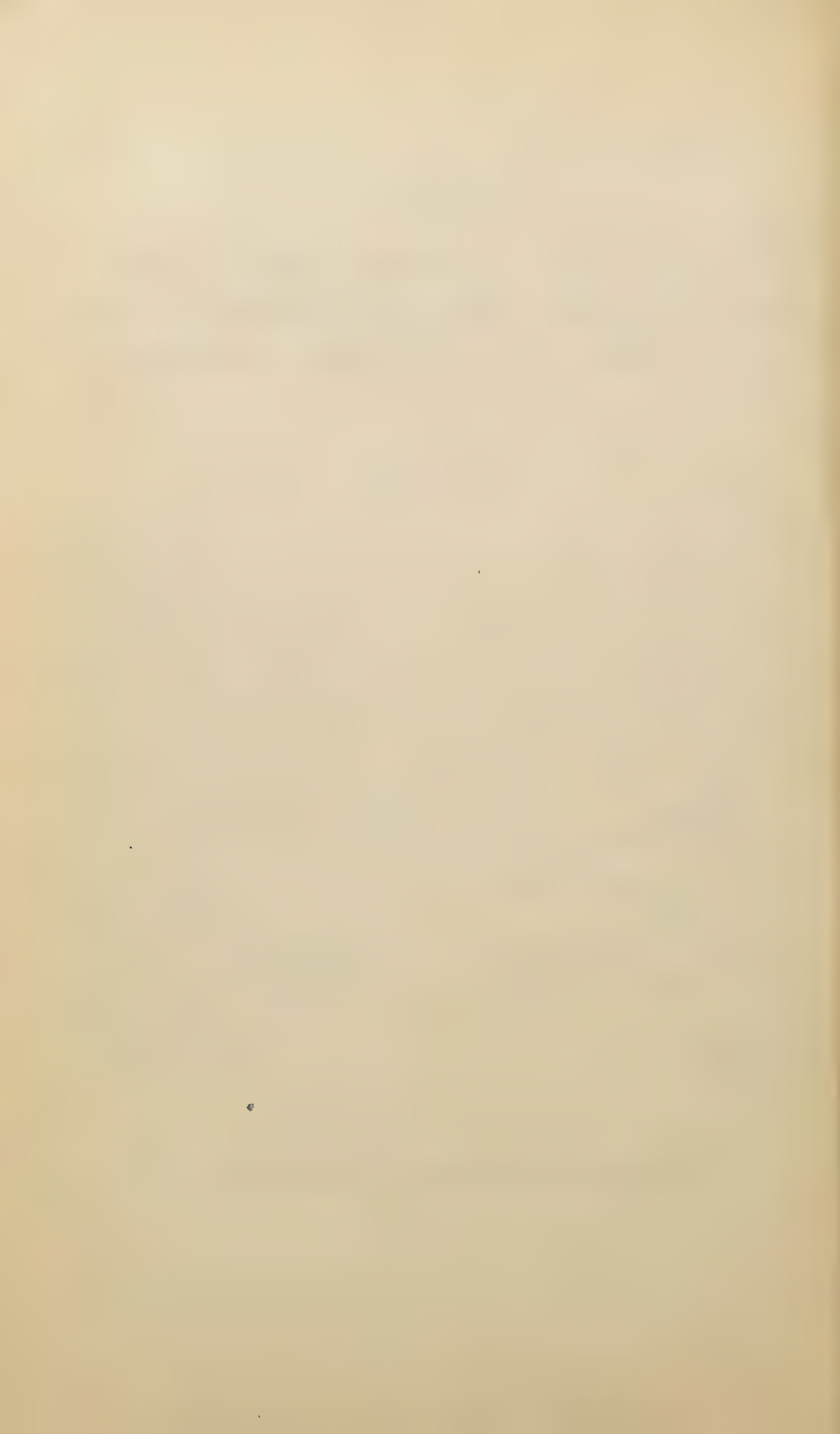
SECTION II.

A SURVEY OF LITERATURE ON THE MANUFACTURE AND PROPERTIES OF IRON AND STEEL, AND KINDRED SUBJECTS.

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Abstractors and translators : Mr. R. A. RONNEBECK and
Dr. D. R. STEINER.



FUEL

The Assay of Coal for Carbonisation Purposes. J. Brown. (Fuel in Science and Practice, 1945, vol. 24, Mar.-Apr., pp. 38-41). The operating technique for the *JB/UAL* carbonisation assay for determining the potential gas yield and gas quality during high-temperature carbonisation is described in detail.

Cokes Utah Coal in Pacific Coast By-Product Ovens. G. E. Stedman. (Steel, 1945, vol. 116, Jan. 29, pp. 84-91). A description is given of the coke-oven practice at the new Fontana Steelworks in California, where there are two batteries each consisting of 45 ovens 40 ft. 6 in. long, 13 ft. high and 14½ in. wide. They are of Koppers-Becker design fired with either blast-furnace or coke-oven gas.

Low-Temperature Coke as an Aid in High-Temperature Carbonisation. (Coke and Smokeless-Fuel Age, 1945, vol. 7, Feb., pp. 31-33). Pilot-plant tests in Germany have shown that, by the addition of 15% of finely ground coke made by carbonising a non-coking coal at a low temperature, hard coke, equal to that produced from a first-class coking coal, could be made by the high-temperature process.

The Value of Dry Quenching of Coke in the Operation of Coke-Oven Plants. W. Scheer. (Iron and Steel Institute, 1945, Translation Series, No. 220). An abridged English translation of a paper which appeared in *Stahl und Eisen*, 1944, vol. 64, Jan. 27, pp. 53-62 is presented. See *Journ. I. and S.I.*, 1944, No. II., p. 140 A.

A Method for Evaluating the Behaviour of Coke in Blast-Furnaces. L. M. Sapozhnikov. (Iron and Steel Institute, 1945, Translation Series, No. 218). An English translation is presented of a report on a Russian investigation of the breakage of coke in transit from the coke-ovens to the blast-furnace and of the physical changes which occur as it descends the blast-furnace. The original paper appeared in *Koks i Khimiya*, 1941, vol. 11, Apr., pp. 1-9.

PRODUCTION OF IRON

The Performance of Large Hot-Blast Stoves. B. B. Frost. (Iron and Steel Engineer, 1945, vol. 22, Feb., pp. 64-69, 79). Operating data on two new blast-furnace stoves are presented and discussed. The stoves were 24 ft. in dia. with a combustion chamber diameter of 6 ft. 11 in.; one was 110 ft. high and the other 100 ft. high. It was established from test runs that, for normal basic iron production, no more than two properly designed stoves are required to ensure reasonable blast temperatures; a third stove is, of course, required to provide for continuity of operation. The blast-heating ability of a group of stoves is determined by the heat storage and heat-transfer capacity of one stove of the group, not by the total heating surface provided for the furnace.

Analysis and Advantages of Operating Furnaces on Dry Blast. L. L. Lewis. (American Society for Metals: Steel, 1945, vol. 116, Jan. 15, pp. 96-98, 122-124). Some advantages of installing equipment to remove moisture from blast-furnace blast are discussed.

Successful Repair of A.I.S. Kembla Blast Furnace. J. W. Thompson. (B.H.P. Review, 1944, vol. 22, Dec., p. 11). **Blast Furnace Repair at 1945—ii**

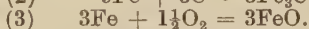
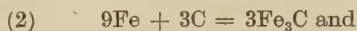
Australian Works. J. W. Thompson. (Iron and Coal Trades Review, 1945, vol. 150, Mar. 30, pp. 467-468). A description is given of a break-out which occurred with No. 2 blast-furnace at the Kembla Works of Australian Iron and Steel, Ltd., and the procedure adopted for its repair.

The Production of Ferro-Chromium in the Blast-Furnace. H. Marenbach. (Stahl und Eisen, 1945, vol. 65, Feb. 1, pp. 57-64). A report is presented of the results of three trials with a small blast-furnace (41 ft. high with a hearth 5 ft. 5 in. in dia.) in the production of ferro-chromium. The burden consisted mainly of Macedonian ores containing up to 27% of chromium which were high in alumina and magnesia. A process was developed by which 30-40% ferro-chromium could be continuously produced, and it was considered to be a useful alternative to the electric-furnace process, by which the heavy war-time demands on the latter furnaces could be reduced. Full details are given of the consumption of ores, fuel and power, the working of the slag, the heat balance and the production.

The Volatilisation of Iron. E. J. Kohlmeyer and H. Spandau. (Archiv für das Eisenhüttenwesen, 1944, vol. 18, July-Aug., pp. 1-6). Experiments are described in which small quantities of almost pure iron were melted in a carbon crucible by a high-frequency current with the object of studying the formation of the vapours evolved. When oxygen is in contact with the surface of molten iron containing about 4.3% of carbon, a thin film of oxide is formed which reacts with the carbon in the iron underneath approximately as follows :



The iron-rich layer thus formed reacts with the carbon below and the oxygen above as follows :



As a result of turbulence a stable condition exists at the surface of the melt in which a gas with the composition FeCO is continuously released; this gas decomposes into iron and carbon monoxide. This process has been compared with the dissociation of Ag_2O evolved from molten silver on which oxygen is blown. The process must be looked upon as an exothermic one, for a brightening of the surface occurs at the spot upon which the stream of oxygen is directed. With iron the phenomenon begins at about 1170° C. (just over the melting point of the iron-carbon bath), and it becomes most active at 1400° C. At above 1500° C. it can no longer be observed.

If the oxygen is supplied in the form of iron-oxide pills put on the surface, equation (3) no longer applies, but this does not prevent the whole process being an exothermic one. A strong exothermic effect must be attributed to reactions (1) and (2). In this case the reactions continue even above 1500° C., because the addition of the cold pills causes a local reduction in temperature.

The above is put forward as a possible explanation of the mechanism of the process. The experiments proved that these surface reactions are not governed solely by the materials and the temperature, but that the manner in which the materials are brought in contact is also important.

Sponge Iron. R. S. Dean. (United States Bureau of Mines, Jan., 1945, Report of Investigations No. 3790). A review is presented of investigations by the Bureau of Mines of methods of making sponge iron and of direct processes of steel production. The two-diameter rotary-kiln method of making granular sponge iron has been improved to yield a low-sulphur iron suitable for steel-making. The method is comparatively simple and the equipment is relatively cheap, but it has not yet been tried out on

a sufficiently large scale for cost estimates to be made. Two variations similar in principle to the Krupp-Renn process have been discovered; these yield an iron of very low silicon content, and are expected to provide a means of making steel from high-phosphorus ores.

Symposium on Production and Design Limitations and Possibilities for Powder Metallurgy Parts. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1788: Metals Technology, 1945, vol. 11, Jan.). The First Conference of the Powder Metallurgy Committee of the American Institute of Mining and Metallurgical Engineers was held on February 21, 1944. The following papers were presented:

Design Factors for the Metal Forms with which Powder Metallurgy May Compete, by F. P. Peters.

Powder Metallurgy as Applied to Machine Parts, by A. J. Langhammer.

Pole Pieces for Electric Motors Made from Iron Powder, by F. V. Lenel.

Bearings from Metal Powders, by W. R. Toeplitz.

Brushes and Allied Powder-Metal Parts, by R. R. Hoffman.

Electrical Contacts Manufactured from Metal Powders, by E. I. Larsen.

Sintered Magnets, by C. R. Fulton.

Friction Articles from Metal Powders, by C. T. Cox.

Certain Characteristics of Silver-Base Powder Metallurgical Products, by F. R. Hensel and E. I. Larsen.

Some Properties of Sintered and Hot-Pressed Copper-Tin Powder Compacts, by C. G. Goetzel.

The Sintering of Metal Powders—Copper, by C. J. Bier and J. F. O'Keefe.

Some Experiments on the Effect of Pressure on Metal-Powder Compacts, by J. F. Kumzick.

FOUNDRY PRACTICE

Gray Iron in the Postwar Period. D. J. Reese. (Gray Iron Founders' Society: Foundry, 1945, vol. 73, Jan., pp. 85, 220-226). The prospects before producers of grey iron castings in the United States are discussed and the need for more accurate data and the exchange of information is stressed.

Foundry Fuel. W. J. Driscoll. (Iron and Steel, 1945, vol. 18, Mar., pp. 75-80). A fuel economy campaign in an imaginary, but none the less typical, iron foundry is described. The method is to make a simple analysis of the fuel input to a foundry, and of the way in which the heat contained in that fuel is expended. Two typical heat-balance diagrams are presented. Many suggestions of a simple and practical nature for reducing the coke consumption are put forward.

Foundry Coke: A Critical Study. B. P. Mulcahy. (Transactions of the American Foundrymen's Association, 1945, vol. 52, Mar., pp. 819-845). See Journ. I. and S.I., 1945, No. I., p. 94 A.

Practical Experiences with the Old-Type Cupola and the New Balanced Blast Cupola. T. Begg. (Institute of Australian Foundrymen: Australasian Engineer, Science Sheet, 1945, Jan. 7, pp. 2-6). Some experiences in the successful operation of a balanced-blast cupola in Australia are

related. The cupola in question was 57 in. in inside dia. and was fitted with three rows of ten auxiliary tuyeres 2 in. in dia. with a single row of ten 5-in. tuyeres underneath them. The main tuyeres were used to make carbon monoxide, which was burnt to carbon dioxide by the auxiliary tuyeres. The melting capacity was 13.3 tons per hr. In practice the melting rate could be varied between 11 and 15.9 tons per hr. by controlling the blast volume and pressure. The temperature of the metal remained consistently high (from 1389° to 1429° C.) from the first tap to the end of the melt. The cupola could be stopped for periods of 30–40 min. without any serious drop in the temperature of the metal. The amount of slag which was “fluxed” or “slagged” away from the slag hole was much more with the balanced-blast cupola than with old-type cupolas. A comparison is made of the costs of operating the two types of cupola, and this shows that when casting 250 tons of metal per annum the savings in the first year balanced the cost of conversion.

The Relationship between Blast Pressure, Blast Quantity and Cupola Dimensions. H. Jungbluth. (Iron and Steel Institute, 1945, Translation Series, No. 214). An English translation is presented of a paper which appeared in *Archiv für das Eisenhüttenwesen*, 1943, vol. 17, July–Aug., pp. 1–4. (See *Journ. I. and S.I.*, 1944, No. II., p. 121 A).

Die Casting Grey Iron in a British Foundry. (Machinery, 1945, vol. 66, Mar. 29, pp. 333–339). The tapping and rotary die-casting practice at the foundry of Qualcast Ltd., Derby, are described and illustrated. The metal is tapped through a siphon brick, the taphole in which is at such a height that metal flows only while the blast is on. The iron is carried from the cupola in 500-lb. ladles to each turntable, where it is transferred into 100-lb. ladles. The metal moulds or dies are mounted on a turntable which makes about 40 revolutions per hr. The dies remain closed until the table carries each one to the knock-out station, where a lever operated by a cam opens them. Scale and dirt are removed by an air blast, after which a coating of soot is deposited on the die cavities by an acetylene burner.

Improvements in Static Ferrous Castings Influencing Their Future Use. G. Vennerholm. (Society of Automotive Engineers: American Foundryman, 1945, vol. 7, Jan., pp. 2–9). Many examples of iron and steel castings are described and illustrated in order to show that the design and properties of such castings have improved so much that they are now used for highly stressed parts in automobile, tank and aeroplane manufacture.

Malleable Castings for Heavy Duty Trucks. P. Dwyer. (Foundry, 1945, vol. 73, Jan., pp. 68–71, 206; Feb., pp. 90–93, 224). An illustrated description is given of the equipment and processes at the new malleable iron foundry of the General Motors Corporation, where castings for heavy military vehicles are made.

Short Cycle Malleabilization of White Cast Iron. E. E. Howe. (Iron Age, 1945, vol. 155, Jan. 18, pp. 66–68). A method for the production of a spheroidised pearlitic malleable cast iron with satisfactory ductility is described. The time required for the malleablising treatment is about half that required in the ordinary process.

Patterns for Propellers. H. J. McCaslin. (Foundry, 1945, vol. 73, Jan., pp. 83–84, 214–218). Methods of making wooden patterns for ships' propellers are described.

Some Patternmaking Considerations. R. L. Simpson. (Institute of British Foundrymen, 1945, vol. 75, Feb. 22, pp. 153–155). Recommendations for economies in patternmaking are put forward.

Uses of Gases in the Foundry. H. Haynes. (Institute of British Foundrymen: Foundry Trade Journal, 1945, vol. 75, Mar. 15, pp. 209–213). The application of town gas or producer gas in foundries for mould, core and ladle drying and other useful purposes is described.

A Foundryman's Notebook. II. Positioning and Securing Cores. (Iron and Steel, 1945, vol. 18, Mar., p. 81). Examples of the size and type of core prints required to secure cores of various shapes in moulds are described and illustrated.

Improvements in Pressure Ferrous Castings Influencing Their Future Use. E. C. Jeter. (S.A.E. Journal, vol. 53, Jan., pp. 19-24). The production of centrifugal castings is described. *See* Journ. I. and S.I., 1945, No. I., p. 146 A.

Ford Development of Centrifugal Casting and Heat Treatment of Aircraft-Engine Cylinder Barrels. (Industrial Heating, 1944, vol. 11, Dec., pp. 1987-2002). The equipment and processes developed by the Ford Motor Co. for the mass production of centrifugally cast cylinder barrels for aero-engines are described with many illustrations.

The Accelerated Cooling of Cast Steels. J. M. Dugan and G. D. Griffiths. (Iron and Steel Engineer, 1945, vol. 22, Jan., pp. 68-78). Theory and experience in the solidification and cooling of cast steel rolls are discussed; the structure to aim at in cast steel rolls and its achievement by a special moulding technique are described. Cast-iron or steel chilling rings set in the flask so as to surround the body of the roll leaving only a thin layer of sand on top do not chill the roll to a sufficient depth. In order to cause the elongated crystals in the rapidly cooled zone to extend farther towards the centre of the roll special water-cooled chills were developed; these were in the form of sets of steel tubes connected to semi-circular headers at each end. Cooling curves are presented which enable the cooling rates of the steel in the feeder head and of solid and water-cooled chills to be compared. These indicate that the rapid absorption of heat by the solid chills was confined to a very short period, and that their effect diminished rapidly after the first 2 hr. With the water-cooled chills the cooling rate was still faster at first, and it remained rapid for about 20 hr. Long experience in the use of water-cooled chills has proved that a fine crystalline structure is obtained to a greater depth and that the life of rolls is considerably improved.

PRODUCTION OF STEEL

Developments in the Iron and Steel Industry during 1944. W. H. Burr. (Iron and Steel Engineer, 1945, vol. 22, Jan., pp. 80-92). A review of the production of the iron and steel industry in the United States in 1944 is presented. The production of pig-iron increased by one million tons to 62,000,000 tons compared with 1943. The total open-hearth ingot output was just under 80,000,000 tons. A little over 4,000,000 tons of electric furnace steel and 5,000,000 tons of Bessemer steel were produced. Some improvements to plant and processes are discussed.

The Iron and Steel Industry on the Niagara Frontier. E. F. Entwisle. (Iron and Steel Engineer, 1945, vol. 22, Jan., pp. 93-98, 104). An account is given of the development of the iron and steel industry along the Niagara River and on the eastern end of Lake Erie.

A History of the Iron and Steel Industry. F. C. Farrell. (Iron and Steel Engineer, 1945, vol. 22, Jan., pp. 99-104).

Present Steelmaking Processes. E. C. Smith. (Metal Progress, 1945, vol. 47, Jan., pp. 79-82). A review of the present steelmaking processes is presented.

Future Changes to be Expected. H. B. Emerick. (Metal Progress, 1945, vol. 47, Jan., pp. 82-83). Developments which are expected to take place in the American iron and steel industry are discussed. These

include: (1) Intensive research and full-scale work on the concentration of lean ores and their reduction in the blast-furnace; (2) a reversion to the Bessemer process with a supplementary deoxidation procedure; (3) operating basic open-hearth furnaces at higher temperatures; and (4) the increased use of mixers and tilting furnaces. No addition to the present electric-furnace steelmaking capacity is expected for some time.

The Future of the British Steel Industry. A. Dunbar. (Sheffield Metallurgical Association: Engineering, 1945, vol. 159, Feb. 23, pp. 145-146; Mar. 16, pp. 204-205; Metallurgia, 1945, vol. 31, Feb., pp. 169-171; Iron and Steel, 1945, vol. 18, Mar., pp. 82-84). The author puts forward his views on the steps to be taken after the war by the British steel industry to ensure full employment and full production. An appeal is made to the steel-consuming industries to consult the producers when their projects are in the design stage. Research on fuel economy, particularly in the production of pig-iron, is advocated and the questions of price and international cartels are discussed.

New Open-Hearth Furnaces at Homestead. H. J. Pugsley. (Iron and Steel Engineer, 1945, vol. 22, Feb., pp. 89-96). An illustrated description is given of the new open-hearth shop at the Homestead Works of the Carnegie-Illinois Steel Corporation. This comprises eleven furnaces with hearths 52 ft. long \times 21 ft. 9 in. wide and two 800-ton hot-metal mixers. Very modern control equipment has been installed.

Flues for Modern Open-Hearth Furnaces. A. G. Arend. (British Steelmaker, 1945, Mar., vol. 11, pp. 128-130). The results of previous investigations of various flue constructions for open-hearth furnaces are re-examined, and some new points added, concerning the shape of bends and corners and the use of "arc splitters" in them. It was found that splitters in the form of 90°-arc units exerted but little influence when close to the inside or outside of the elbow. Until a certain minimum value had been reached in each elbow tried at all velocities, the single splitter reduced the loss caused with increase in radius ratio; beyond this point, however, the contrary tended to become evident. The best results were achieved by using two splitters instead of one. Splitters with a radius ratio of 0.4 were most suitable for flues with mitre elbows.

Operates Open Hearths on All Scrap-Carbon Charge. P. S. Kingsley. (Steel, 1945, vol. 116, Jan. 22, pp. 106-109). A detailed account is given of the operation of a 50-ton basic open-hearth furnace on an all-scrap charge with carbon additions.

Comparative Investigations into the Effect of Special Deoxidisers on Dead Soft Steel. P. Zimmermann. (Iron and Steel Institute, 1945, Translation Series, No. 210). An English translation is presented of a paper which appeared in *Mitteilungen der Kohle- und Eisenforschung G.m.b.H.*, 1935, vol. 1, Nov., pp. 29-48. (See *Journ. I. and S.I.*, 1936, No. 1, pp. 125 A).

The Improvement of the Citric-Acid Solubility of Basic Open-Hearth Slags Containing Fluorspar. T. F. Pearson. (Iron and Steel Institute, 1945, this Journal, Section I). Brief mention is made of the citric-acid solubility test for basic slags. A survey of the order of solubility for slags from both fixed and tilting furnaces when fluorspar is used follows. Tapping-slags were found to be 10-20% soluble for fixed furnaces and 20-30% soluble for a tilting furnace with current practice. Preliminary experimental work was conducted to discover the effect of quenching, and it was found by this means that the solubility could be increased considerably. The severity of the quench appeared to influence the results. Further work in the laboratory involved the sintering of powdered low-solubility slags with sodium carbonate and other sodium compounds. The former proved to be the most effective and, by the use of a sufficient quantity, any slag could

be rendered completely soluble. The efficiency of the sodium carbonate became less as the initial solubility of the slag with which it was sintered increased. Laboratory experiments involving the treatment of slags at high temperatures with steam proved unfruitful.

Results obtained from the sintering experiments prompted full-scale trials in the pitside, and numerous treatments were carried out by feeding sodium carbonate and mixtures of sodium carbonate with sand into slag ladles at tapping. A satisfactory method of sampling these ladles while the slag was liquid was evolved, and it was found that, in spite of the difficulties resulting from a lack of precise knowledge of the actual slag weights, considerable increases in solubility values were obtained.

In the discussion of the results it is suggested that the efficacy of the sodium carbonate depends on its more complete dissociation at high temperatures than the other sodium compounds used. The interpretation of the mechanism of increased solubility is based on the acceptance of the "insoluble" phosphorus existing as $3(3\text{CaO} \cdot \text{P}_2\text{O}_5) \cdot \text{CaF}_2$ (slightly soluble only). The addition of sodium carbonate results in a substitution of some, or all, of the bonded CaF_2 , with the probable formation of $3(\text{CaO} \cdot \text{P}_2\text{O}_5) \cdot 2\text{NaF}$, or possibly the loosening of the fluoride molecule. Later laboratory experiments disproved the possibility of the formation of sodium phosphate up to the limit of sodium carbonate used, since no "water solubility" resulted from any treatment. Additions of sand made in the full-scale trials appeared to have some slight effect in increasing the solubility, probably by increasing the tendency towards the formation of some soluble silico-phosphate.

Full-scale trials indicated that, in order to keep down the proportion of sodium carbonate to reasonable amounts, the addition of fluorspar to the furnace would have to be limited to some 4 cwt., approximately, for an 85-ton charge.

Analytical Survey of a Rimming Steel Ingot. J. S. Vatchagandhy and G. P. Contractor. (Iron and Steel Institute, 1945, this Journal, Section I). A $5\frac{1}{2}$ -ton ingot of rimming steel containing 0.11% of carbon and 0.45% of manganese was sectioned along the vertical axis for analytical survey and sulphur-printing. The results of chemical analysis made with reference to the distribution of carbon, manganese, sulphur and phosphorus do not appear to indicate any significant departure from the known trend of variations of the segregating elements from the outside to the centre of the ingot and from the bottom to the top.

A Table giving theoretical carbon and oxygen percentages at the balanced composition, calculated according to the expression given by Binnie (Journ. I. and S.I., 1942, No. II., p. 283 F), for some of the rimming-steel ingots of which data have been published was prepared. The theoretical carbon percentage at the balanced composition for the present ingot was calculated to be 0.0714%, 0.0875% and 0.101% at 1, 1.5 and 2 atm., respectively.

The average carbon content of the entire core was 0.17%, as compared with the ladle figure of 0.11%, and that of the rim zone was about 0.09%. The average carbon content of the ingot as a whole was 0.150%. Since this figure should normally be below the ladle-analysis figure, in view of the concept that the iron-oxide/carbon reaction is mainly responsible for a decrease in the carbon content of the rim zone, the inference is drawn that the ladle carbon content recorded was very low.

FORGING, STAMPING AND DRAWING

Recent Developments in Forging Practice. W. W. Dyrkacz and L. B. Fonda. (Steel, 1945, vol. 116, Jan. 22, pp. 82-85, 124; Jan. 29, pp. 79-80, 110-116; Feb. 5, pp. 128-131, 166-170; Feb. 12, pp. 104, 139-150). A comprehensive review of the forging practice at the works of the General Electric Co. is presented. It covers raw material, die design, steam and pneumatic hammers, heat-treatment and testing.

Metallurgical Control of Aircraft Forgings. A. J. Pepin. (Society of Automotive Engineers: Steel Processing, 1944, vol. 30, Dec., pp. 771-779).

Metallurgical Control of Forging. A. J. Pepin. (Steel, 1945, vol. 116, Jan. 15, pp. 76-77, 88-92). A detailed description is given of the organization and methods of control at the works of the Wyman-Gordon Co., Worcester, Massachusetts, makers of high-quality steel forgings for aircraft.

Forging on a Spot Welder. G. W. Birdsall. (Steel, 1945, vol. 116, Feb. 19, pp. 106-107, 146-152). The adaptation of a 135-kVA. resistance welding machine for small forging and riveting work is described.

Upset Forging with the Flash Welder. H. J. Malee and G. C. Close. (Steel Processing, 1944, vol. 30, Dec., pp. 791-793, 805). The application of flash butt-welding machines for the upset forging of bars and tubes is described.

Forging Automobile Crankshafts on High Speed Mechanical Presses. (Steel Processing, 1945, vol. 31, Jan., pp. 49-51, 60). The successful development of the forging of automobile crankshafts in dies in a 2500-ton press with a 14-in. stroke working at 50 strokes per min. is described and illustrated.

Modern Aspects of Drop Forging. H. Haller. (Zeitschrift des Vereines deutscher Ingenieure, 1943, vol. 87, Dec. 25, pp. 809-814). Recent German developments in the drop-forging process are described. One of these is called the "splitting" process, by which a section suitable for drop forging is simply split from the billet of raw material instead of drawing the blank approximately to the shape of the die. Examples of this and other methods by which difficult shapes can be constructed with less machining time are described and illustrated. (An English translation of this paper appeared in Machinery, 1945, vol. 66, Mar. 22, pp. 313-317; Apr. 5, pp. 369-371).

Forging Die Design. J. Mueller. (Steel Processing, 1945, vol. 31, Jan., pp. 31-33). Examples are given of the design of dies for drop forgings which can subsequently be flash-butt-welded together in order to build up intricate shapes.

Pressure Control Gage for Hydraulic Presses. C. W. Hinman. (Steel Processing, 1945, vol. 31, Jan., pp. 35, 46). A gauge with an adjustable maximum pointer for controlling the pressure on the ram of a hydraulic press is described. The maximum hand is pre-set at the pressure required to perform the work; when this is reached an electric circuit operates a relay connected to a solenoid; the latter trips a spring mechanism on a valve which causes the ram to be released.

Electric Drives for Power Presses. (Sheet Metal Industries, 1945, vol. 21, Mar., pp. 453-455). Descriptions are given of electric motors and drives with push-button control for crank-type variable-pressure presses working with a comparatively short stroke.

Carbide Die Applications. A. R. Zapp. (Wire and Wire Products, 1945, vol. 20, Jan., pp. 35-41, 81-83). The development of tungsten-carbide dies for nail mills and cold-heading operations is described.

Deep Drawing 0.67-Inch Plate. G. R. Reiss. (Steel, 1945, vol. 116, Jan. 22, pp. 92-96). An illustrated description is given of the sequence of

pressing operations which was developed for making mortar bombs from blanks of 0.10% carbon steel plate $4\frac{1}{2}$ in. in dia. and 0.67 in. thick.

Steel Cartridges of 3-In. Caliber. F. M. Arnold. (Metal Progress, 1945, vol. 47, Jan., pp. 67-74). The sequence of processes in the drawing and heat-treatment of 3-in. dia. steel cartridge cases is described.

Deep Drawing of Wind Shields for Heavy Calibre Shells. (Steel Processing, 1945, vol. 31, Jan., pp. 26-27). A brief description is given of the drawing processes involved in the manufacture of windshields for 15-in. dia. shells out of sheet metal. These shields are 34 in. long and involve very deep drawing.

The Manufacture and Metallurgy of Seamless Drawn Steel Tube. E. H. Francis. (Australian Institute of Metals: Australasian Engineer, Science Sheet, 1945, Jan. 8, pp. 9-14). Methods of drawing, heat-treating and testing seamless steel tubes are described and illustrated.

Tests to Determine and Predict the Power Required in the Bright-Drawing of Steel. W. Lueg and A. Pomp. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1944, vol. 27, No. 4, pp. 43-52). An investigation is described the purpose of which was to develop a simple method of predicting the energy required for the bright-drawing of steel bars. Bars of twelve different types of steel of different diameters were drawn down to 17 mm. in dia., using a steel die with an entry angle of 20° , the drawing force being measured in each case. From the tensile stress at the exit end of the die and the mechanical properties of the bars before drawing, a number of relationships were calculated; of these, that between the longitudinal stress at the die exit and the Brinell hardness were least affected by the type of steel. From this fact, and on the basis of the test results, a formula for the drawing force was developed which incorporated the Brinell hardness, the final cross-section and the reduction in area. The results obtained by this formula can be converted so as to apply to other die angles by making use of previously established relationships between die angles and drawing forces. A diagram is presented which enables the drawing force for a given set of conditions and other technical data to be read off without making laborious calculations.

ROLLING-MILL PRACTICE

The Electronic Frequency Changer. F. W. Cramer, L. W. Morton and A. G. Darling. (Iron and Steel Engineer, 1945, vol. 22, Jan., pp. 52-62). Electronic apparatus has been developed at the works of the Carnegie-Illinois Steel Corporation with which an adjustable but constant amount of electric power can be transferred between power systems of different frequencies. The installation, consisting of two 10,000-kW. duplicate electronic frequency changers, is used to interconnect a 44-kV. 25-cycle system with a 69-kV. 60-cycle system. The apparatus is described and its principles explained. It is used in rolling-mill power stations.

The Universal Slabbing Mill at Homestead. A. G. Ericson. (Iron and Steel Engineer, 1945, vol. 22, Mar., pp. 35-44). A description is given of a mill recently completed at the works of the Carnegie-Illinois Steel Corporation for rolling slabs from $2\frac{1}{2}$ to 20 in. thick and from 20 to 62 in. wide. The main rolls are 45 in. in dia. \times 80 in. long, and these are direct driven through universal spindles. It is a universal mill with vertical rolls 36 in. in dia. \times 80 in. long; these are driven through easily detachable couplings to facilitate roll changes.

Structural Mill at the Fontana Plant of the Kaiser Company, Inc., Has Initial Annual Capacity of 200,000 Tons. R. M. Bickerstaff. (Blast

Furnace and Steel Plant, 1945, vol. 33, Feb., pp. 223-231). A description of the new rolling mills at Fontana, California, with a lay-out plan and numerous illustrations is presented. There are two mills, one a two-high reversing roughing-mill stand with 36-in.-dia. rolls driven by a 5000-h.p. D.C. motor, and the second consisting of roughing, intermediate and finishing stands driven by another 5000-h.p. motor.

Structural Mills and Structural Roll Designing. R. E. Beynon. (Iron and Steel Engineer, 1945, vol. 22, Feb., pp. 35-52). Descriptions are given of the development of rolling-mill lay-outs and of pass designs for rolling joists, angles, channels and Z bars.

Unitemper Mill and Process. M. D. Stone. (Iron and Steel Engineer, 1945, vol. 22, Jan., pp. 37-47; Blast Furnace and Steel Plant, 1944, vol. 32, Dec., pp. 1457-1459). **New Unitemper Mill and Process.** M. D. Stone. (Steel, 1944, vol. 115, Dec. 11, pp. 132-134). The unitemper mill consists of two independent 2-high mills, one mounted above the other. The strip of steel is continuously stretched between the two mills, and thereby obtains the required temper-hardness, ductility and flatness. The maximum speed of the experimental mill is 3000 ft. per min., but higher speeds are contemplated for future installations.

The Place and Effect of Conveyor Equipment in Industry. J. E. McBride. (Iron and Steel Engineer, 1945, vol. 22, Feb., pp. 70-76). Some engineering shop and steelworks' applications of continuous conveyor systems, in particular a hot strip coil conveyor, are described and illustrated.

HEAT TREATMENT

Reactions between Hot Steel and Furnace Atmospheres. F. E. Harris. (Metal Progress, 1945, vol. 47, Jan., pp. 84-89). Reactions that commonly occur between hot steel and furnace atmospheres are discussed from the standpoint of simple thermodynamics. The free-energy values involved in eleven reactions and the corresponding values of $\log K_p$ are tabulated, K_p being an equilibrium constant defined as the product of the partial pressures of the reactants divided by the partial pressure of the product. The use of these two factors in studying the reactions involved in the formation of methane, the decomposition of carbon monoxide, the water-gas reaction, the formation of iron oxides from iron and carbon dioxide or water vapour, and carburising is dealt with.

Application of Controlled Atmospheres to Metal Processing. C. E. Peck. (American Society of Mechanical Engineers: Steel Processing, 1944, vol. 30, Nov., pp. 729-735, 748; Dec., pp. 801-804). The properties of the following heat-treatment furnace atmospheres and the equipment for their production are described: (1) Completely burned fuel gas; (2) partially burned fuel gas; (3) partially reacted or cracked fuel gas; and (4) partially burned dissociated ammonia. Recommendations are made on the most suitable atmospheres for annealing ferrous and non-ferrous metals.

Queen City Steel Treating Company Performs Wide Diversity of Treatments. E. P. Stenger. (Steel Processing, 1945, vol. 31, Jan., pp. 21-25). A description is given of the furnaces and heat-treatment equipment at the works of the Queen City Steel Treating Company in Cincinnati.

Continuous Heat Treating of Armor Steel Castings. E. F. Cone. (Metals and Alloys, 1944, vol. 20, Dec., pp. 1593-1597). An illustrated description is given of the large heat-treatment plant built at the works of the General Steel Castings Corporation for the treatment of hull castings for army tanks.

These castings are 22 ft. long and 10 ft. wide and vary greatly in thickness. Cup-shaped incandescent ceramic gas-burners have been incorporated in the side-walls of the heat-treatment furnaces.

Surface Hardening and Brazing with the Induction Heater. G. C. Close. (Steel Processing, 1945, vol. 31, Jan., pp. 43-46). Induction-heating equipment for the hardening of gear teeth and other parts, as well as for brazing, is described.

New Tocco Laboratory Devoted to Study of Induction Heating. (Industrial Heating, 1944, vol. 11, Dec., pp. 2030-2034). A description is given of the new experimental and development laboratory of the Tocco Division of the Ohio Crankshaft Company. It is equipped with twenty-four testing stations supplied with current at frequencies ranging from 960 to 1,000,000 cycles per sec.

High Frequency Induction Heating New Tool for the Metal Working Industry. A. O. Wood. (Steel Processing, 1944, vol. 30, Dec., pp. 795-799). "Tocco" units for the induction heat-treatment of steel bars are described.

Induction Tempering in the Rolling-Mill. H. Krainer. (Stahl und Eisen, 1945, vol. 65, Feb. 15, pp. 95-100). The hardening of bars from the rolling temperature in the mill has already been successfully accomplished. Investigations are now in progress on the possibility of tempering in the mill so that the production of hardened and tempered bars can be carried out in the rolling-mill department. In this paper a report on tempering by induction heating in the rolling-mill is presented. The results were favourable from an economic point of view, as the current consumption was only 140-200 kWh. per ton of bars. The tests were made on low-alloy chromium vanadium steel. The impact strength of bars with a tensile strength exceeding 100 kg. per sq. mm. was better than that of bars tempered by the usual processes. The tensile and impact properties of bars tempered by induction heating and by other processes are compared in Tables and by series of curves.

Normalizing of Welds in Carbon-Molybdenum Steel Pipe by 60-Cycle Induction Heating. D. H. Corey and I. A. Rohrig. (Welding Journal, 1945, vol. 24, Jan., pp. 1-S-6-S). The results of tests are reported in which welded joints in carbon-molybdenum steel pipes 14 in. in outside dia. with a wall thickness of 0.937 in. were normalised locally by 60-cycle induction-heating equipment. The normalising was satisfactorily performed with this equipment. The heat-affected area resulting from this treatment was many times wider than that caused by the welding. Owing to the short heating time, only a thin layer of scale was formed inside the pipe at the hottest section.

Summerill Tubing Co. Improves Induction Heating Setup for Heat-Treating Tubing Continuously. I. H. Such. (Steel, 1945, vol. 116, Feb. 12, pp. 94-95). A brief description is given of a continuous heat-treatment machine for steel tubes of small diameter. Heat is supplied from a 30 kW. H.-F. spark-gap induction heating unit with a frequency range of 100,000-300,000 cycles per sec. The tubes are fed through the heating coil at 8-10 ft. per min.

Induction Heating. G. W. Birdsall. (Steel, 1945, vol. 116, Feb. 26, pp. 80-81, 112-116). Induction heating equipment for hardening crankshafts and gears at the works of the Briggs and Stratton Corporation, Milwaukee, is described and illustrated.

Job Shop for Induction Heating. R. Baubie. (Steel, 1945, vol. 116, Jan. 8, pp. 120, 136). It is pointed out that once the basic equipment for induction heating is installed, i.e., the expensive transformers, rectifiers and oscillators, a wide variety of jobs can be undertaken by merely changing the inductor coil, which is the least expensive item of the equipment.

Heat-Treating Fasteners. (Steel, 1945, vol. 116, Jan. 29, pp. 76, 104-108). A description is given of the continuous heat-treatment plant with chain-belt conveyors at the works of the National Screw and Manufacturing Co., Cleveland, Ohio, where large quantities of bolts, studs, &c., are made.

Copper Plate as a Stop-Off When Nitriding. W. V. Sternberger and E. R. Fahy. (Metal Progress, 1945, vol. 47, Feb., pp. 278-279). Tests are described in which steel bushes were coated with different thicknesses of copper and then subjected to a nitriding process for 72 hr. at 965° F. The minimum thickness of copper which effectively prevented nitriding of the steel was found to be about 0.0004 in.

WELDING AND CUTTING

Adams Lecture—Solid-Phase Welding. A. B. Kinzel. (Welding Journal, 1944, vol. 23, Dec., pp. 1124-1143). The bonding mechanism in welds made by pressing the parts together at temperatures below the melting point is explained. A series of pressure welds was made commencing at temperatures slightly above the upper critical point and followed by a tensile test at a slightly lower temperature; the welding and testing were done at progressively decreasing temperatures; the material consisted of 1-in.-dia. bars of 0.25% carbon steel. Welds made at 925° C. for 30 sec. showed a maximum bonding strength of 19,000 lb. per sq. in. at the testing temperature; this was only 58% of the strength of the parent metal at the same temperature. As the strength of the parent metal decreased with increased testing temperature, the strength ratio of the interface bond increased to 86% for the welds tested at below the critical temperature. There was evidence that the strength of the bond was materially increased by allowing the weld to cool through the critical range. The results of several more series of tests at various temperatures on pressure welds are reported and discussed. The mechanism of pressure welding seems to be based on the transfer of atoms across the interface. The hypothesis that the laws of diffusion apply to this transport of atoms appears to be both plausible and tenable. The dispersion of the interface oxide film can also be treated as a diffusion problem.

Welding of Dissimilar Metals. W. Spraragen and D. Rosenthal. (Welding Journal, 1945, vol. 24, Feb., pp. 65-S-85-S). A comprehensive review of the literature on the welding of dissimilar metals is presented. The review covers American literature to January 1944 and that of other countries to January 1941. The bibliography contains 130 references.

Welding and Cutting in Steel Plant Maintenance. S. D. Baumer. (Iron and Steel Engineer, 1945, vol. 22, Feb., pp. 80-88). A variety of welding and cutting maintenance jobs in a steelworks are described and illustrated. These include hard-facing shear blades, roller guides, coke-pusher shoes, crane tong bits, dies and die-holders, as well as the making of new equipment such as all-welded ladles.

High Lights of Hard-Facing Procedure. R. L. Lerch. (Welding Journal, 1945, vol. 24, Feb., pp. 139-143). Numerous examples of the increased life to be obtained by depositing Stellite on edges and surfaces subjected to severe wear are described and illustrated.

Flash Welding S.A.E. 4130 Steel Tubing. W. Pestrak and W. W. Ackerman. (Iron Age, 1945, vol. 155, Jan. 25, pp. 46-49). Machines for the flash-welding of chromium-molybdenum steel tubes are described and illustrated.

Flash-Butt Welding—Welding Technique and Variables in Welding Low-Alloy Steels. J. J. Riley. (Welding Journal, 1945, vol. 24, Jan.,

pp. 12-S-24-S). A comprehensive description of the flash-butt welding process is given, together with several Tables and curves relating to current consumption, flashing time and the mechanical pressure applied.

Flash Welding of Alloy Steels—Physical and Metallurgical Characteristics. J. C. Barrett. (Welding Journal, 1945, vol. 24, Jan., pp. 25-S-44-S). Extensive investigations of the properties of flash-welded joints in bars and thick-walled tubes of chromium-molybdenum and other low-alloy steels are described. Non-metallic inclusions were frequently present in the thick-walled tubes; in flash-welding these caused craters which lowered the strength and ductility of the joint. A technique for welding in hydrogen was developed which prevented the formation of these oxides. The effects of various heat-treatments before and after welding were demonstrated.

Problems in Spot Welding of Heavy Mild Steel Plate. F. R. Hensel, E. I. Larsen and E. F. Holt. (Welding Journal, 1945, vol. 24, Jan., pp. 46-S-57-S). An investigation of the effect of the welding conditions on the properties of spot welds in $\frac{1}{2}$ -in. hot-rolled mild steel plate is reported. Of the four shapes of electrode tested the best results were obtained with electrodes $1\frac{1}{2}$ in. in dia. rounded to a 2-in. radius with a $\frac{1}{2}$ -in.-dia. flat across the nose.

Electrode Tip Wear in Spot Welding Mild Steel. W. S. Simmie. (Iron Age, 1945, vol. 155, Feb. 1, pp. 48-51). A series of experiments on the wear of electrode tips for the spot-welding of mild steel are described. The optimum shape of tip was found to be a truncated cone with a base angle of 30°. Chromium-copper electrodes were found to last longer than cadmium-copper electrodes.

Oxyacetylene Pressure Welding. A. R. Lytle. (Welding Journal, 1945, vol. 23, Dec., pp. 1145-1156). An illustrated description is given of the process of oxy-acetylene pressure welding in which flat clean surfaces are pressed together under a pressure of about 3000 lb. per sq. in., while a narrow zone on each side of the junction is heated with multi-flame torches to about 1250° C.; the metal is then upset to a controlled degree, and an excellent weld is formed. The equipment for different types of work is described and the results of hardness surveys and other tests are given. Steels of almost all types, including stainless steel and some non-ferrous metals and alloys, can be successfully welded by this method.

Producing Gas-Welded Tubing from 2500-Pound Coils of Strip. J. N. Bohannon and F. Judelsohn. (Steel, 1945, vol. 116, Feb. 26, pp. 84, 102-105; Mar. 5, pp. 124-125, 140-142). A description is given of a new continuous mill for producing tubing from steel strip. The mill drive can be adjusted to move the strip at any speed between 5 and 65 ft. per min. At present strip 0.109 in. thick is welded at 12 ft. per min. and 0.065-in. strip at 35 ft. per min. The seam is oxy-acetylene welded by a line of burners consisting of 160 orifices arranged to provide preheating, heating and welding zones. After welding, the tube passes through sizing rolls; it is then given a preliminary quench by small jets of water before passing into a tunnel in which cooling is continued by compressed air, the amount and pressure of which are controlled to give the desired hardness. The tube passes next through sizing and straightening rolls to the cutting-off machine.

Tool Steel Welding. E. L. Foote. (Iron Age, 1944, vol. 154, Dec. 7, pp. 70-74). The construction and repair of tools and dies by welding with tool-steel electrodes are discussed. In many cases the cooling in air of the metal deposited gives the temper required without further heat-treatment.

Repair of Castings. L. A. Danse. (Welding Journal, 1944, vol. 23, Dec., pp. 1119-1123). Representatives of the Office of the Chief of Ordnance in Detroit, the Detroit Ordnance District and the Detroit Inspector of Naval Material recently attended joint meetings of the

General Motors' Foundry and Welding Committees which drew up specifications for the repair of automobile castings. These have been embodied in Engineering Bulletin No. 152, which is reproduced in this paper. It is in two parts, one entitled "Repair of Defective Automotive Gray Iron Castings" and the other "Shop Procedure for Repairing Apparent Imperfections in New Automotive Gray Iron Castings."

Thermit Welding in Heavy Fabrication. K. Rose. (Metals and Alloys, 1944, vol. 20, Dec., pp. 1620-1624). Several applications of the thermit welding process are described and illustrated. These include: (1) Welding steel tie-bars 7 × 7 in. in section; (2) welding the stern frame of a ship; (3) butt-welding lengths of rail in a tunnel; and (4) building up worn wobblers on rolls. The process has also been used for demolition purposes where explosives would be too dangerous; it can be applied, for instance, to melt through the columns supporting large structures.

The Identification of the Constituents of Welding Electrode Coatings. R. C. Vickery. (Metallurgia, 1945, vol. 31, Jan., pp. 119-123). A scheme for identifying the constituents of welding electrode coatings which utilises their mineralogical, magnetic and chemical attributes is outlined.

The Effect of Residual Stresses and Multidirectional Constraint upon the Behavior of Welded Structures under External Load. (Welding Journal, 1944, vol. 23, Dec., pp. 648-S-656-S). An account is given of work done under a research programme at the National Bureau of Standards under the auspices of the Structural Steel Research Committee of the Welding Research Council of the American Welding Society. The investigations cover bend tests on box girders and tests on several types of T joint for connecting the deck of a ship to the sheer strake of the hull.

Impact Strength of Arc-Welded Joints in Aircraft Steel. H. O. Klinker. (Welding Journal, 1945, vol. 23, Dec., pp. 633-S-634-S). Data are presented on the impact strength of butt-welded joints in chromium-molybdenum steels used in American aeroplane manufacture.

The Measurement of Energy Absorption in the Tee-Bend Test. L. C. Bibber and J. Heuschkel. (Welding Journal, 1945, vol. 23, Dec., pp. 609-S-632-S). A detailed description is given of the T bend test for welds developed by the United States Navy Department; the account includes the preparation of the specimens, the testing machines, the method of measuring the energy absorbed in bending and the presentation of results.

Fatigue Strength of Butt Welds in Ordinary Bridge Steel—Maximum Stress Compressive. (Welding Journal, 1945, vol. 24, Jan., pp. 7-S-9-S). The results are reported of several series of compression-tension fatigue tests on butt-welded specimens of $\frac{7}{8}$ -in. plate of steel containing not more than 0.25% of carbon.

The Effect of the Weld-Bead Shape on the Tensile-Fatigue Strength of Tube Welds. M. Werner, K. Dangel and B. Klotz. (Stahl und Eisen, 1945, vol. 65, Feb. 1, pp. 64-67). The results of tensile-fatigue tests on butt-welded joints in steel tubes are reported. Tubes of 0.23% plain carbon steel and of a chromium-molybdenum steel were used. A wide variety of joint types welded by the gas and electric processes were tested. The tensile-fatigue strength of the joint depends to a great extent on the shape of the prepared surfaces. The Y-shaped joint should not be used, as this has a low fatigue strength. The V-shaped joint welded with good penetration has a high fatigue strength; this is, however, surpassed when a ribbed backing strip with the rib projecting into the bottom of the V is used. Steels with more than 0.3% of carbon should not be used for tubes which are to be welded. Good electric and gas welds can be made in low-alloy heat-resisting chromium-molybdenum steel with welding rods of similar composition to that of the parent metal. Welding in a protective atmosphere does not improve the fatigue strength.

Effect of Time of Storage on Ductility of Welded Test Specimens. C. E. Jackson and G. G. Luther. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1772: Metals Technology, 1945, vol. 12, Jan.). It has been observed that when making bend and tensile tests on welded specimens the ductility of the metal improved with increasing time intervals between welding and testing. Some tests made with the object of studying this phenomenon are reported. Tests on specimens which were treated in liquid air after welding so as to decompose any retained austenite also showed improved ductility with time, so that the gradual decomposition of austenite was not the cause. Specimens welded with 25/20 chromium-nickel steel electrodes did not increase in ductility on prolonging the time interval. The ductility of specimens was considerably increased by storage at 85° and 100° C. One theory is that the improvement is due to the removal of residual hydrogen from the steel, and another is that it is the result of the relief of stresses.

Tensile Properties of Longitudinally Welded Plate. L. C. Bibber. (Society of Naval Architects and Marine Engineers: Steel, 1945, vol. 116, Jan. 15, pp. 80-86, 129-133). A report is presented of an investigation of the behaviour and strength of longitudinally welded ship's plates and angles. Very large testing equipment was used, so as to accommodate welded specimens of the same size and shape as the welded joints incorporated in ship construction.

Recent Applications of Oxyacetylene Processes in Steel Foundries. G. E. Bellow. (Welding Journal, 1945, vol. 24, Jan., pp. 25-35). Oxy-acetylene cutting operations in a steel foundry are reviewed. These include examples of the use of a "radiograph" cutting machine for removing gates and risers, flame-scarfing to remove metal from large surfaces, and flame-gouging or deseaming to remove defects.

Multiple and Stack Machine Cutting. A. H. Yock. (Welding Journal, 1945, vol. 24, Feb., pp. 127-138). A survey is presented of the development in the United States of oxy-acetylene cutting machines some with one burner for cutting a stack of thin plates clamped together, and others with several burners for cutting identical shapes out of thicker plate. Many modern machines are described and illustrated.

CLEANING AND PICKLING OF METALS

Blast Treatment of Metals for Cleaning and Peening. E. L. Cady. (Metals and Alloys, 1944, vol. 20, Dec., pp. 1588-1592). Equipment for the shot-blasting of metals is described and its application for cleaning and improving the fatigue strength of machine components is discussed.

How Cadillac Uses Production Shot Peening. R. L. Orth. (Steel, 1944, vol. 115, Dec. 7, pp. 89, 131). An illustrated description is given of the shot-peening plant for small connecting rods which has been set up by the Cadillac Motor Co., Detroit.

Electrolytic Methods of Polishing Metals. S. Wernick. (Sheet Metal Industries, 1944, vol. 20, Sept., pp. 1541-1548; Nov., pp. 1913-1917; Dec., pp. 2095-2098; 1945, vol. 21, Mar., pp. 443-446). Continuation of a series of articles (see Journ. I. and S.I., 1944, No. II., p. 167 A). In Parts IV. and V. the electrolytic brightening of nickel coatings on zinc-base die castings and the electrolytic polishing of aluminium are dealt with. Bright zinc plating is described in Part VI. in which reference is made to an acid zinc-sulphate electrolyte of the following composition:

ZnSO ₄ .7H ₂ O	:	:	:	430 g. per litre
Al ₂ (SO ₄) ₃ .18H ₂ O	:	:	:	30 g. per litre
Na ₂ SO ₄ .10H ₂ O	:	:	:	50-150 g. per litre

To this is added 3-5 g. per litre of 2.6 or 2.7 sodium naphthalene disulphonate. The pH value of this solution is maintained at between 4 and 4.5, and the current density employed at a bath temperature which is below 25° C. varies from about 30 to 80 amp. per sq. ft. This solution is advocated for bright zinc plating by the Russian investigators N. T. Kudryavtsev and A. A. Nikiforova.

Electrolytic Polishing. S. Wernick. (Steel, 1944, vol. 115, Dec. 11, pp. 146-148, 176-180). The method and application of electrolytic polishing of stainless steel are described. H. H. Uhlig experimented with various solutions, temperatures and current densities of the electrolyte, but experimental work is by no means complete, especially as a number of difficulties will have to be overcome, such as maintaining the optimum conditions of operation, and controlling the bath-temperature. It is also shown that parts with sharp angles, bends, or recesses are unsuitable for electrolytic polishing.

The Present Status of Electropolishing. J. S. Crout. (Metal Progress, 1945, vol. 47, Feb., pp. 259-264). The extension of electrolytic polishing to spheres beyond that of polishing metallographic specimens is discussed; these applications include obtaining better adherence for plated or enamelled coatings, and finishing parts to closer tolerances than those possible with the finest machine tools. The economic aspects are considered. Electrolytic polishing is most advantageous economically when it can be used to replace several operations, such as descaling, removing burr, tumbling and wheel polishing.

Wider Uses for Castings Through Surface Preparation. J. H. Shoemaker and H. G. Webster. (Transactions of the American Foundrymen's Association, 1945, vol. 52, Mar., pp. 768-781). Some particulars are given of a process of preparing the surface of cast iron (machined or unmachined) so that a good bond is obtained in the subsequent lead-tin alloy coating process. The part is first immersed in an oxidising bath which converts the impurities at the surface to oxides; it is then put in a reducing bath held at 220°-250° F. to remove the oxides without exposing any additional graphite. This is followed by a rinse in boiling water and dipping for 15-60 sec. in 10% hydrochloric acid. A zinc-ammonium-chloride flux is applied to the surfaces to be coated. A lead-tin alloy containing only 5% of tin can be successfully applied after this treatment.

The Pickling of Steels. Part IV. Bulk Storage of Acid. Part V. Lifting and Agitating Mechanism. E. W. Mulcahy. (Sheet Metal Industries, 1945, vol. 21, Feb., pp. 257-261; Mar., pp. 437-442). Continuation of a series of articles (see Journ. I. and S. I., 1945, No. I., p. 129 A). The construction of tanks for storing sulphuric and hydrochloric acids, the design of suitable semi-automatic and automatic acid flow meters, conveyor systems, lifting devices and acid agitators are described.

Glass Tanks for Pickling and Plating. G. L. West. (Metals and Alloys, 1945, vol. 21, Feb., pp. 413-416). Descriptions are given of glass-lined and all-glass pickling tanks made of special glass heat-treated by the Herculite process to increase its strength and resistance to thermal shock.

Pickling in the Vitreous Enamelling Industry. N. Swindin. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1945, vol. 75, Apr. 5, pp. 273-279). The chemistry and physics of hydrochloric acid and sulphuric acid pickling baths are explained, and descriptions are given of the rubber-lined tanks, the Noristaltic glandless pump for pickling acids and liquors, fume extraction equipment and the Curran spray pickling machine.

COATING OF METALS

Film in Chromium Electroplate. J. B. Cohen. (Electrochemical Society, Oct., 1944, Preprint No. 28). Evidence is described which proved the existence of films existing in the crack system which develops in electrolytic chromium plating on steel. When the deposit was heated to 482°C . the isolated films were more easily handled than those from the unheated plate, but the characteristics of the films were different in the two cases. The films taken from unheated chromium plating were very friable and transparent and had a yellowish-brown colour as observed in the aggregate; their composition could not be determined. The films isolated from the heated chromium were brittle but not friable; they were transparent, bi-refrangent and dielectric, and were green when observed in the aggregate; these films were studied by spectrographic analysis, microchemical analysis and the X-ray diffraction technique and were found to consist of Cr_2O_3 ; their weight amounted to about 0.05% of that of the chromium deposit.

Laminating Steel and Cupro-nickel. J. V. Kielb. (Steel, 1945, vol. 116, Jan. 8, pp. 114-118). A description is given of processes of bonding cupro-nickel (copper 70%, nickel 30%) sheet to mild-steel plate. Spot and plug welding were tried, but with little success because of warping. The best method was brazing. After thorough degreasing and cleaning, both the surfaces to be joined are uniformly coated with a flux; a thin sheet of copper is placed on the fluxed steel surface, the cupro-nickel sheet is placed on this and weights are placed on top. The pack is then passed slowly through a hydrogen brazing furnace held at 2050°F .

Hot Dip Lead Coatings for Steel. J. L. Bray. (Steel, 1944, vol. 115, Dec. 18, pp. 110-112). Descriptions are given of processes of coating steel with lead and lead alloys. A good lead coating is obtained by hot-dipping into molten lead held at $690\text{--}710^{\circ}\text{F}$. covered with flux consisting of an $\frac{1}{8}$ -in. layer of zinc ammonium chloride, but the adhesion of the coating is much better if there is 0.55% of zinc in the lead.

Evaluation of Strip Plating Solutions. D. A. Swalheim. (Electrochemical Society: Steel, 1944, vol. 115, Dec. 7, pp. 102-104). A description is given of the rotating cathode cell with which the effect of different plating solutions and other plating conditions on the cathode efficiency can be determined; the results obtained are applied in the design and operation of continuous tinning plants for steel strip.

Filming Tinplate—A New Rust-Prevention Method. B. W. Gonser. (Modern Packaging, Nov., 1944). The very thin tin coatings deposited on steel by the electrolytic process soon rust on exposure because of minute pinholes. Protection from the rusting of the outside of food cans has been obtained by dipping in a quick-drying lacquer or in a wax emulsion.

Some Observations on the Structure of Acid-Resistant Vitreous Enamels for Chemical Plant. G. E. Charlish and E. J. Heeley. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1945, vol. 75, Feb. 15, pp. 127-130; Feb. 22, pp. 147-152; Mar. 1, pp. 173-178). Investigations have been made into the characteristics of acid-resisting enamels supplied for chemical plant purposes with the object of ascertaining the reason for the somewhat erratic behaviour of enamelled plant under operating conditions. The high-frequency spark test was applied, and revealed the presence of defects undetectable by visual examination and the "wet" electrical methods of testing enamelled surfaces. Microscopic examination of the spot indicated as faulty by the spark test enabled typical defects to be located accurately. Metallographic examination of sections of enam-

elled coatings showed that the majority of the defects found by the spark test were voids extending through the full thickness of the enamel.

New Vitreous Enameling Alloy Steel Developed. (Steel Processing, 1944, vol. 30, Dec., pp. 783-784). Some particulars are given of a titanium-bearing steel developed by the Inland Steel Co., Chicago, which can be enamelled in a light colour without a ground coat and still have an excellent finish. The steel also has good deep-drawing properties.

New Titanium Steel for Vitreous Enameling. G. F. Comstock and E. Wainer. (Iron Age, 1945, vol. 155, Feb. 15, pp. 60-63, 152, 153). The procedure for making, pickling and enamelling titanium-stabilised steel sheets is described. The steel is completely deoxidised with aluminium before adding the low-carbon ferro-titanium. From 69% to 87% of the titanium is recovered in the finished steel. When the proper precautions are taken an excellent finish with a single coat of enamel can be obtained.

The Scope and Limitations of Radiant Heating in Drying Processes. H. Silman. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1945, vol. 75, Mar. 8, pp. 195-198; Mar. 15, pp. 217-221). Descriptions are given of equipment for the rapid drying of paints and enamels by banks of electric lamps emitting infra-red rays and by incandescent gas-burners. A series of curves shows the difference in the time required to heat up metal plates coated in different colours. The economics of the process are discussed.

Continuous Oven Installed in Steel Landing Mat Production Line. C. A. Litzler. (Industrial Heating, 1944, vol. 11, Nov., pp. 1878-1888). A plant is described in which rolls of slotted steel strip used for aeroplane landing mats are degreased, painted and baked by a continuous mass-production process.

PROPERTIES AND TESTS

Gray Iron—Its Economy, Adaptability and Versatility Viewed as an Engineering Material. R. G. McElivee. (American Foundryman, 1945, vol. 7, Jan., pp. 12-16). The properties of cast iron are reviewed with the object of pointing out those which are of most value in engineering specifications.

Modern High-Duty Cast Iron. E. W. Harding. (Machinery, 1945, vol. 66, Mar. 8, pp. 255-258). The reliability of modern high-duty cast iron as an engineering material is discussed; its good machinability, density, wear-resistance and its fluidity in the molten state are described.

Metallurgical Aspects of Machine-Tool Castings. J. G. Ritchie. (Institute of Australian Foundrymen: Foundry Trade Journal, 1945, vol. 75, Mar. 22, pp. 231-234; Mar. 29, pp. 251-255). A comprehensive review of the properties of cast iron, with special reference to its suitability for machine-tool castings, is presented.

Quality Control. B. P. Dudding and W. J. Jennett. (Institute of Metals: Metal Industry, 1945, vol. 66, Mar. 2, pp. 130-133; Mar. 9, pp. 146-149). The evaluation of test data by statistical methods in the metallurgical industries for controlling the quality of products is explained.

Quality Control of Enameling Steels. R. F. Bisbee. (Steel, 1945, vol. 116, Feb. 26, pp. 82-83, 118-128). The system developed by the Westinghouse Electric and Manufacturing Co. for inspecting, testing and controlling the quality of the steel they purchase for subsequent enamelling is described.

The Use of Wire-Wound Electrical Resistance Strain Gauges, as Applied to Engineering Problems, for the Measurement of Static Strains. S. F. Dorey.

(Transactions of the Institution of Naval Architects, 1944, vol. 86, pp. 61-71). The measurement of static strains using electrical resistance strain gauges in conjunction with a Wheatstone bridge and a cathode-ray oscillograph is described. Stresses as low as 250 lb. per sq. in. can be readily measured under workshop conditions provided the correct technique is applied. Methods of calibrating the equipment and its use in two specific problems are discussed.

Self-Indicating Torsion Testing Machines. (Engineering, 1945, vol. 159, Apr. 6, p. 267). Two new torsion testing machines developed by W. and T. Avery, Limited, one hand operated and the other motor driven, are described.

Investigations of the Cold-Plasticity and Sensitivity to Ageing of Deep-Drawing Steel Sheets. F. Eisenkolb. (Stahl und Eisen, 1945, vol. 65, Mar. 15, pp. 137-141). A mechanical device which can be built into a universal testing machine is described; it enables strips of steel sheet to be cold-rolled under tension while the roll pressure and the tension are measured. Strips of steel sheet of various compositions made by different processes were cold-reduced and then given a deep-drawing test. The increase in strength due to cold-work was greater with basic-Bessemer steel than with open-hearth steel, especially after normalising or annealing. Ageing tests are described in which steels sensitive to ageing cracked suddenly on deep-drawing. Only the cold-worked and aged basic-Bessemer sheets, especially after normalising, were prone to cracking in this test. In some cases an increase in the nitrogen and phosphorus contents of the steel contributed to the failure of the specimens. Annealing in hydrogen was the most effective method of overcoming this.

Graphitization of Low-Carbon and Low-Carbon-Molybdenum Steels. H. J. Kerr and F. Eberle. (American Society of Mechanical Engineers: Welding Journal, 1945, vol. 24, Feb., pp. 86-S-122-S). The failure of a high-pressure steam pipe of a low-carbon molybdenum steel has led to extensive investigations of the causes of graphitisation of low-carbon steels. The results of many service and laboratory tests are reported in this paper. Steels deoxidised with more than 1.5 lb. of aluminium per ton were very fine-grained and graphitised in service, whilst silicon-killed steels and those killed with less than 0.5 lb. of aluminium per ton did not graphitise. Abnormal and normal carbon-molybdenum steels showed little, if any, graphite after 5½ years' service at 935-950° F. or after 4 years at 1050° F. except when the abnormal steel had been heated and cooled through the lower critical range by welding or during heat treatment. Abnormal carbon-molybdenum steels could be graphitised in the laboratory by holding at 1000° F. for 1000 hr. Increasing the rates of heating and cooling appeared to favour the formation of graphite stringers. Normal carbon-molybdenum steel subjected to repeated cycles of heating and cooling did not develop graphite after subsequent holding at 1000° F. for 6000 hr. The McQuaid-Ehn grain-size test provided valuable information on the graphitising tendency of steel. A coarse-grained normal carbon-molybdenum steel with an addition of 0.4-0.6% of chromium is recommended for high-temperature steam plant. A large number of micrographs of test sections are shown and an extensive bibliography is appended.

Fatigue and Tensile Test Specimens Prepared by Grinding. (Iron Age, 1945, vol. 155, Jan. 18, p. 57). Two grinding machines for preparing steel specimens for fatigue and tensile tests are described. For the fatigue specimens the machine has a 7-in.-dia. grinding wheel with its axis at right-angles to that of the specimen so that the wheel marks will be in the same direction as the specimen axis.

Fatigue Tests at Resonant Speed. R. E. Rawlins. (Metal Progress, 1945, vol. 47, Feb., pp. 265-267). A description is given of an apparatus for

applying rapidly alternating stresses to a new type of coupling. A resonant repeated-loading unit consisting of two massive flywheels connected by a "coupling spring" was developed. The specimen was mounted at the middle of the spring and formed part of it. The driving force was supplied by an electromagnetic vibration motor driven from an oscillator and power amplifier.

Shot Blasting to Increase Fatigue Resistance. J. O. Almen. (S.A.E. Journal, 1943, vol. 51, July, pp. 248-268). See Journ. I. and S.I., 1944, No. I., p. 102 A.

Damping Capacity—A General Survey of Existing Information. F. C. Thompson. (British Non-Ferrous Metals Research Association, 1944, Research Report No. 657). Present knowledge of the fundamentals of damping capacity, such as its metallurgical and mechanical significance and the validity of present methods of determining it, is reviewed and suggestions for future experimental work are made.

Dependence on Stress of Damping Capacity of Alloys. A. Gemant. (Mechanical Engineering, 1945, vol. 67, Jan., pp. 33-38). A mathematical study of the relationship between creep and damping and their dependency on stress is presented, with particular reference to the effect of additions of silicon to steel on its damping capacity.

Air Hardenability of Steel. C. B. Post, M. C. Fetzer and W. H. Fenstermacher. (American Society for Metals: Steel, 1945, vol. 116, Mar. 5, pp. 120-121, 132-139). Methods of testing and of specifying the hardenability of air-hardening steels are described. To obtain a range of cooling rates along single specimens an assembly was developed which consisted of a cylinder of a nickel-iron alloy 6 in. long \times 6 in. in dia. with a hole through the centre tapped at each end; two specimens of the steel to be tested, each 7 in. long \times 1 in. in dia., were screwed into the 6-in. cylinder so as to meet in the middle of it, leaving 4 in. protruding at each end. The assembly was heated in a hardening furnace, soaked at the desired temperature and cooled in air. Flats were ground on the 1-in.-dia. specimens at increasing distances from the face of the 6-in.-dia. cylinder, and Rockwell hardness tests were made at these positions which represented previously determined cooling rates. The results of tests on several chromium-nickel and chromium-nickel-molybdenum steels are presented and discussed.

Rockwell Hardness (Diamond Penetrator) of Cylindrical Specimens. W. L. Fleischmann and R. S. Jenkins. (Metal Progress, 1945, vol. 47, Feb., pp. 275-276). Tests are described the purpose of which was to establish a relationship between the Rockwell hardness measured on a cylindrical surface and on a flat surface of the same steel, so that it would not be necessary to grind one or two flats on cylindrical parts in order to test them. A large number of tests were made on bars of different diameters tempered to hardnesses in the C-25-C-55 range, and curves for the required relationship were drawn.

Magnetic Measurement of the Hardenability of Carbon Toolsteels. C. B. Post and W. H. Fenstermacher. (Metal Progress, 1945, vol. 47, Feb., pp. 286-288). A hardenability test for shallow-hardening steels using a 5-in. specimen tapering from $1\frac{1}{4}$ in. down to $\frac{1}{4}$ in. in dia. has been described previously (see Journ., 1941, No. II., p. 52 A). In order to save time in grinding and making Rockwell tests on these specimens an electromagnetic apparatus has been developed by which the hardenability of such specimens with carbon in the 0.80-1.30% range can be rapidly determined. The apparatus is described and illustrated.

A Table for Comparing Different Hardness Scales. B. Rinman and E. Löwgren. (Jernkontorets Annaler, 1945, No. 1, pp. 33-36). (In Swedish). The Vickers, Brinell and Rockwell methods of hardness-testing are dis-

cussed, and a Table for converting test results from one scale to another is presented.

Latest Recommended Practice for Checking Commercial Forgings by Magnetic Particle Inspection. (Steel, 1945, vol. 116, Mar. 5, pp. 126-128, 174-187). The equipment and technique for the magnetic-powder testing of heavy forgings, particularly hollow steel shafts and columns, are described and illustrated.

The Permanent Magnet. D. Taylor. (Journal of the Junior Institution of Engineers, 1945, vol. 55, Mar., pp. 159-168). The manufacture, testing and properties of permanent-magnet alloys are described and discussed.

Vital Inspections of Aircraft Parts Made by Supersonic Measurement. W. S. Erwin. (Steel, 1945, vol. 116, Mar. 5, pp. 131, 188-192). A description is given of the "Sonigage," an instrument which enables the thickness of metal within the 0.02-0.40-in. range to be measured with an accuracy of 2% when only one face of the metal is accessible. The apparatus consists of a simple variable-frequency electronic oscillator connected to a quartz crystal which is placed on the metal surface and applies high-frequency mechanical vibrations to it.

The Adsorption of Gases on Smooth Surfaces of Steel. J. B. Austin and Marion H. Armbruster. (Journal of the American Chemical Society, 1944, vol. 66, Feb. 10, pp. 159-171). The adsorption on cold-rolled steel of argon, neon, hydrogen, nitrogen, carbon monoxide and carbon dioxide has been determined at 20°, -78°, -183° and -195° C., and at pressures up to 1 mm. of mercury. Measurements were made first on a degreased surface from which the gas had been removed, and subsequently on the same surface after reduction by hydrogen. Neither hydrogen nor neon was measurably adsorbed on either surface. A monomolecular layer of physically-held nitrogen, argon or carbon monoxide was adsorbed on the unreduced surface at -183° F., but in each case approximately 15% of the total volume of gas adsorbed was held so strongly that it could not be removed by reducing the pressure at the same temperature. A similar monolayer of physically-held nitrogen and argon was adsorbed on the reduced surface, but it could be entirely removed by evacuation of the system. On this same surface a complete monolayer of physically-held carbon monoxide was adsorbed, together with a partial layer of chemically-adsorbed molecules. Force-area curves for the adsorbed films show that, when some of the gas is held to the surface very strongly, phase-transformations similar to those occurring in monomolecular films on water may take place.

The Strength Properties of Case-Hardening Steels after Different Heat-Treatments. H. Cornelius. (Archiv für das Eisenhüttenwesen, 1944, vol. 18, July-Aug., pp. 23-27). The results of tensile, impact and bending-fatigue tests on smooth and notched specimens of case-hardening steels after various forms of heat-treatment are presented and discussed. The steels tested contained up to 1.5% of manganese, up to 1.3% of chromium and up to 0.2% of molybdenum.

Chart of Comparable Tool Steels. R. G. Sartorius. (Iron Age, 1945, vol. 155, Feb. 1, pp. 44-47). A Table of tool-steels produced in the United States is presented. It gives their trade names, the names of the manufacturers and details of their applications, heat-treatment and composition.

Mechanism of the Influence of Silicon on the Quality of Chromium Constructional Steel. S. T. Kishkin. (Iron and Steel Institute, 1945, Translation Series, No. 219). An English translation is presented of a paper which appeared in *Izvestiya Akademii Nauk S.S.S.R.*, 1943, No. 5-6, pp. 78-83. It presents the results of impact tests on low-chromium steels containing various amounts of silicon and heat-treated in different ways.

Silicon arrests the process of carbide formation in the tempering of chromium steel.

Effect of Boron on Machinability and Hardenability. T. G. Harvey. (*Iron Age*, 1945, vol. 155, Feb. 15, pp. 52-54). The effect of additions of about 0.002% of boron on the machinability and hardenability of 0.40-0.50%-carbon free-machining steel was investigated. The results are given in Tables and curves. In general, the hardenability was increased by 31% and the machinability was reduced by about 5%.

Some Cases for Steel as a Material. E. P. Strothman. (*Society of Automotive Engineers: Steel Processing*, 1945, vol. 31, Jan., pp. 39-42, 48). Examples are given of the redesign of aeroplane parts, so as to make use of the strength of low-alloy steel. In one case it was found advantageous to make a bomber nose frame of alloy steel instead of using magnesium castings.

The Investigation of Steels for Cold-Heading Tools for Bolt Making. E. Lickteig. (*Stahl und Eisen*, 1945, vol. 65, Feb. 15, pp. 85-95). An investigation by torsional impact tests and bending fatigue tests of steels suitable for the dies used in cold-heading bolts in two-stroke presses is described. Six tool steels containing 0.90-1.12% of carbon, some of which were alloyed with up to 1.4% of chromium and up to 0.26% of vanadium, as well as a case-hardened steel, were tested. The vanadium steels proved to be particularly wear-resisting. Data on the test results and heat-treatments are presented.

Enemy Material from the Metallurgical Point of View. J. R. Cady, H. W. Gillett and L. H. Grenell. (*Metal Progress*, 1945, vol. 47, Feb., pp. 289-320). Information resulting from the examination of captured German and Japanese munitions, tanks and aeroplane engines is presented. It includes notes on the materials used, especially the substitutes for nickel and copper, and hardness surveys across sections of shells and bullets.

Enemy Metallurgical Practice. J. H. Frye. (*Society of Automotive Engineers: Steel*, 1945, vol. 116, Feb. 19, pp. 108-111, 154-160). A description is given of some of the steels and processes developed by the Japanese and the Germans for constructing parts of military equipment.

METALLOGRAPHY AND CONSTITUTION

New Method of Mounting Metallographic Specimens. U. J. Hochschild. (*Metals and Alloys*, 1944, vol. 20, Dec., pp. 1614-1615). A method of mounting a number of wire specimens on end in a small block of plastic material for examination under the microscope is described.

Improved Sensitivity in Double Exposure Radiography. J. Rigbey. (*Canadian Metals and Metallurgical Industries*, 1945, vol. 8, Jan., pp. 20-23). In a former paper the author described a technique by which the vertical distance of a flaw from the surface of a metal could be calculated. Two exposures on a single film were necessary. In the improved method described in this paper two films are used instead of a double exposure on one, whereby the sensitivity is improved from 4% to 1%.

Radiography and Its Application to the Foundry Industry. C. H. Hauser. (*American Foundryman*, 1945, vol. 7, Jan., pp. 17-20). The advantages and limitations of X-rays and γ -rays for the inspection of castings are compared.

Casting Eight Inches Thick Examined in Three and One-Half Minutes by Two Million Volt X-Ray Unit. (*Steel*, 1945, vol. 116, Jan. 15, pp. 95, 120). Brief particulars are given of a 2,000,000 V. X-ray apparatus developed for metallurgical purposes by the General Electric Co., Schenectady.

Interpreting Aircraft Casting Radiographs. L. W. Ball. (American Society for Metals: Foundry, 1945, vol. 73, Feb., pp. 83-85, 192-198). See Journ. I. and S.I., 1945, No. I., p. 64 A.

CORROSION OF IRON AND STEEL

Metal Corrosion and Its Prevention. R. R. Rogers. (Canadian Metals and Metallurgical Industries, 1944, vol. 7, Dec., pp. 20-22, 25). Many methods of preventing the corrosion of metals are briefly reviewed and the corrosion-testing equipment at the laboratories of the Bureau of Mines in Ottawa are described.

Laboratory Tests to Predict the Performance of Metals under Service Conditions. D. W. Sawyer and R. B. Mears. (Industrial and Engineering Chemistry, Analytical Edition, 1945, vol. 17, Jan., pp. 1-5). Laboratory corrosion tests are described in which the effect of petrol and various oils on metals and the effect of metals on petrol and oils were studied. Copper accelerated the decomposition of cracked fuels at room temperature and the decomposition of lubricating oil at higher temperatures. Aluminium alloys and stainless steel were generally inert in these tests.

Protective Value of Electro-Tin As an Undercoating. S. Wernick. (Journal of the Electrodepositors' Technical Society, 1944, vol. 20, pp. 47-60). An extensive investigation of the effect of a tin undercoating before electro-depositing a coating of zinc, cadmium or nickel on the corrosion resistance is reported. Samples of sheet steel 6 in. \times 2 in. with one end turned up at 90° were plated and submitted to a hot-water immersion test, an intermittent salt-spray test and to outdoor exposure in an industrial atmosphere. The zinc and cadmium deposits, both direct on the steel and on top of tin, withstood the hot-water test satisfactorily; the nickel deposits, however, were all attacked. In the salt-spray and out-door exposure tests the superior resistance of the composite coating was clearly established in all cases. The coating thicknesses were selected so that composite coatings of the same thickness as single coatings of zinc, cadmium and nickel could be compared. The possible cause of the beneficial effect of the tin was studied. It was found that the thickness of the zinc, cadmium and nickel coatings without tin fell off markedly along the length of the specimen as the angle was approached, particularly in the case of nickel, and that the tin caused the thickness to be much more uniform.

Intergranular Corrosion of Stainless Steel Welds. W. T. Tiffin. (Welding Journal, 1945, vol. 24, Feb., pp. 125-S-128-S). The conditions governing the formation of chromium carbides and leading to the failure of welds in stainless steel are discussed. When the weld cools slowly through the 1600-1100° F. range the precipitation of carbides is extensive; this can be corrected by reheating to between 1900° and 2100° F., cooling rapidly through the above range and then applying a normalising or spheroidising treatment.

Antifouling Paints—Effect of Inert Pigment on Antifouling Action. G. H. Young, W. K. Schneider and G. W. Seagren. (Industrial and Engineering Chemistry, Industrial Edition, 1944, vol. 36, Dec., pp. 1130-1132). Anti-fouling paints were prepared containing different proportions of leafed copper powder and barytes, and two brush coats were applied on sand-blasted steel panels with two primary coats of a chromate-type phenolic paint. These panels were exposed at Daytona Beach and examined monthly for seven months. The addition of inert pigment to

copper-bearing formulations increased their anti-fouling efficiency. The mechanism of the anti-fouling action is governed to a great extent by the permeability of the vehicle employed, for this controls the rate at which the soluble toxic arrives at the paint-water interface. The ideal formulation is one combining permeability, exfoliation rate and toxic concentration in such a manner that the toxic is not wasted on initial exposure and is released at a fairly constant rate to yield concentrations just above the lethal threshold value at the paint-water interface. Commercially available ship's bottom paints were tested, and the short service life of some of them was attributed, not to a deficiency in toxic agents, but to an improper balance of vehicle permeability with the toxics employed. Some paints were improved by additions of celite which imparted higher diffusion rates to the films, but the majority had too high a permeability and wasted toxic in the first months of exposure.

Corrosion Ratings of Metals. (Steel, 1945, vol. 116, Jan. 22, pp. 98-104). See Journ. I. and S.I., 1945, No. I., p. 88 A.

BOOK NOTICES

American Iron and Steel Institute. "*Iron and Steel Industry. Position Descriptions and Classifications.*" 4to. New York: The Institute.

The information contained in this series of volumes, was compiled at the request of the War Production Board, Washington, by the American Iron and Steel Institute, from data supplied by leading companies. Particulars are given of the occupational titles and duties of all those engaged in the different departments of American iron and steel plants. The common position title of each individual and other titles which might be used for the position held are given, together with a description of typical duties. The relative importance to the industry of an individual in a particular job is shown in terms of the average training period. The volumes, several of which have appeared in the revised edition, cover the following departments: No. 1. Coke Plant; No. 2. Blast-Furnace; No. 3. Open-Hearth Furnace, Bessemer Converter, Electric Furnace; No. 4. Blooming, Slabbing and Billet Mills. Blooming and Slabbing Mills. Billet Mill; No. 5. Rod and Wire Mills. Rod Mill—Wire Mill; No. 6. Maintenance. Administrative and Departmental; No. 7. Parts I & II. Maintenance Shops; No. 8. Utilities. Operation and Maintenance; No. 9. Plate Mills; No. 10. Hot Sheet Mill. Hot Strip Mill. Cold Strip Mill; No. 11. Sheet, Strip and Tin Finishing; No. 12. Bar and Shape Rolling, and Finishing; No. 13. Wire Finishing; No. 14. Packaging and Shipping; No. 15. General Labour and Yard Transportation; No. 16. Foundry Products; No. 17. Heat Treating, Forging and Machining. Forged Products. Rolled Armour Plate; No. 18. Rail Mill, Wheel and Axle Mills; No. 19. Quality Control. Metallurgical and Chemical Inspection; No. 20. Tube Making and Finishing; No. 21. Structural Mill; No. 22. Plant Administration.

Chesters, J. H. "*Steelplant Refractories.*" Testing, Research and Development. 8vo, pp. xi + 509. Illustrated. Sheffield, 1944: The United Steel Companies, Ltd. (Price 36s.).

Preliminary Notice.—This is the first text-book to appear dealing exclusively with steelplant refractories. The author was the first student in this country to receive a Ph.D. degree for a thesis on refractory materials, and for the last twelve years has been with the United Steel Companies, Ltd., in charge of the Refractories Section of the Central Research Department. The book describes the methods found useful in the testing of refractories, the properties of the principal materials used and the conditions existing in steelplant furnaces. A section is included on the statistical treatment of test data, and there are also twenty-one appendices giving information needed by the refractories technologist in his day-to-day work. For a more detailed review see pp. 101 A-102 A.

Gill, J. P., R. S. Rose, G. A. Roberts, H. G. Johnston and R. B. George. "*Tool Steels*." 8vo., pp. 577. Illustrated. Cleveland, 1944: American Society for Metals (Price \$6.00).

The Preface states that "the purpose of this book has been to present as concisely as possible both the theoretical and practical information which exists on the more commonly used types of tool steel" and that it has been written for those who use tool steels in the hope that "the data given will be of material help to them in becoming better acquainted with the many types of tool steels produced and in solving tool problems". It can be said at once that the authors—who are all members of the metallurgical staff of the Vanadium-Alloys Steel Co.—have succeeded admirably in their task.

The first seven chapters deal generally with tool steels, their history and development, their manufacture in crucible, electric and basic open-hearth furnaces, their hot working, heat-treatment and testing, their classification and selection, and the purpose and effect of the principal alloying elements added to them. The remaining eleven chapters deal with specific groups of tool steels, commencing with carbon steels, and passing through various low-alloy steels—such as chromium steels, non-deforming steels, silicon steels, tungsten finishing steels, graphite steels—up to die steels and high-speed steels. The book is literally a mine of useful information, and bears obvious signs of having been written by men who know their job. Whenever possible data are given graphically—there are some 240 diagrams in the book—while the macrographs and photomicrographs which are included are not only excellent examples of the art, but tell an essential part of the story—they are not just decorative.

The text has, of course, been written largely round American practice, and possibly some of the steels listed may not be so familiar to English readers; doubtless some of the data given could be criticised, but there is no doubt at all that as a treatise on tool steels, their properties and everything concerning them, the book merits the highest praise.

J. H. G. MONYPENNY.

Ungewitter, C. "*Science and Salvage*." From the German "*Verwertung des Wertlosen*." Translated by L. A. Ferney and G. Haim. With an Introduction by Dr. E. F. Armstrong, F.R.S. 8vo., pp. 183. London, 1944: Crosby Lockwood & Son, Ltd. (Price 12s. 6d.).

The book "*Verwertung des Wertlosen*" was published in Berlin in 1938, and consisted of a series of treatises published in "*Die Chemische Industrie*", reprinted under the Editorship of Dr. Claus Ungewitter, with a foreword by Goering. It reviews the whole field of Germany's achievement in the production of valuable materials from the air, the sea, and the forest, and her relentless salvage of raw material from every kind of waste. The book, which describes conditions in and prior to 1938, and would to-day be subject to revision, contains the following chapters: (1) Introduction. Making the Worthless Valuable; (2) Wealth from the Air; (3) The Sea as a Source of Raw Materials; (4) The Utilisation of Low-Grade Mineral Resources; (5) Problems of Peat Utilisation; (6) Forestal Products; (7) Agricultural Wastes; (8) Utilisation of Scrap and Worn Materials; (9) Municipal Refuse; (10) Raw Materials from Salvage; (11) Utilisation of By-products from Chemical Manufacturing; and (12) Coal Ash—an Undeveloped Source of Raw Materials.

BIBLIOGRAPHY

AMERICAN IRON AND STEEL INSTITUTE. "*Iron and Steel Industry. Position Descriptions and Classifications*." 4to. In 23 volumes. New York: The Institute.

AMERICAN WELDING SOCIETY. "*Guide to the Weldability of Steels*." Pp. 90. New York, 1944. The Society. (Price \$1.00.)

AMERICAN WELDING SOCIETY. "*Glossary of Foreign Welding Terms*." Compiled by M. A. Cordovi. Pp. 16. New York: The Society. (Price 50 cents.)

BROOKE, E. H. "*Chronology of the Tinplate Works of Great Britain*." 8vo, pp. 177. Cardiff, 1944: William Lewis (Printers), Ltd. (Price 8s.)

- BUTLER, J. C. "*Sheet Metal Theory and Practice.*" Pp. 173. New York: John Wiley and Sons, Inc. (Price \$3.00.)
- CURTIS, F. W. "*High-Frequency Induction Heating.*" Pp. 243. Illustrated. New York: McGraw-Hill Book Co., Inc. (Price \$2.75.)
- DESCH, C. H. "*The Past and Future of Steel.*" (The Cleveland Scientific and Technical Institution. Inaugural Harold Wright Lecture.) 8vo. Pp. 22. Middlesbrough, 1944.
- GOTTWEIN, K., und W. REICHEL. "*Kühlen und Schmieren bei der Metallbearbeitung.*" 3. Aufl. 8vo, pp. 89. Berlin, 1944: VDI-Verlag G.m.b.H. (Price 4.85 R.M.)
- HIBBEN, T. "*The Sons of Vulcan.*" London: T. Werner Laurie.
- JIMENO, EMILIO. "*Química General.*" 2e Edición. 8vo, pp. xv + 842. Madrid, 1944: Sociedad Anonima Española de Traductores y Autores. (Price 85 pesetas.)
- KLEINSCHMIDT, B. "*Das Schleifen in der Metallbearbeitung.*" 2 Aufl. 8vo, pp. xi + 575. Berlin, 1944: Technischer Verlag Herbert Cram. (Price 16 R.M.)
- MALLEABLE FOUNDERS' SOCIETY. "*American Malleable Iron.*" A Handbook. 8vo, pp. viii + 367. Illustrated. Cleveland, Ohio, 1944: Malleable Founders' Society.
- MASING, G. "*Ternary Systems, Introduction to the Theory of Three-Component Systems.*" Translated by B. A. Rogers. Pp. 173. New York, 1944: Reinhold Publishing Corp. (Price \$4.50.)
- METALLISATION, LTD. "*The Mark 16 Metal-Spraying Pistol.*" A Practical Handbook on its Installation and Operation, also The Use of Metal Sprayed Coatings. 8vo, pp. 45. Illustrated. Dudley, 1945: Metallisation, Ltd. (Price 5s. 6d.)
- MINISTRY OF FUEL AND POWER. "*Coal Mining. Report of Technical Advisory Committee.*" 8vo, pp. ix + 149. London, 1945: H.M. Stationery Office. (Price 1s.)
- MINISTRY OF FUEL AND POWER. "*Durham Coalfield. Regional Survey Report (Northern 'B' Region).*" 8vo, pp. 48, with Map. London, 1945: H.M. Stationery Office. (Price 1s.)
- MYKLESTAD, N. O. "*Vibration Analysis.*" Pp. 316. New York: McGraw-Hill Book Co., Inc. (Price \$3.50.)
- PATERSON, D. G. P., and J. BEARN. "*An Outline of Industrial Metallurgy.*" 8vo, pp. viii + 185. Illustrated. London, 1944: Chapman & Hall, Ltd. (Price 12s. 6d.)
- REASON, R. E., M. R. HOPKINS and R. I. GARROD. "*Report on the Measurement of Surface Finish by Stylus Methods.*" Leicester: Taylor, Taylor and Hobson, Ltd. (Price 30s.)
- REDMAYNE, SIR RICHARD A. S. "*The Problem of the Coal Mines.*" London: Eyre and Spottiswoode (Publishers), Ltd. (Price 4s. 6d.)
- REICH, H. J. "*Theory and Applications of Electron Tubes.*" 2nd Edition, pp. 716. Illustrated. New York: McGraw-Hill Book Co., Inc. (Price \$5.00.)
- SINGER, T. E. R. "*German-English Dictionary of Metallurgy.*" 8vo, pp. 298. New York: McGraw-Hill Book Co., Inc. (Price \$4.00.)
- Svedberg, The. 1884-1944. 8vo, pp. 731. Illustrated. Uppsala, 1944.
- TAGGART, A. F. "*Handbook of Mineral Dressing.*" Vol. I. "*Ores and Industrial Minerals.*" 8vo, pp. viii + 1915. Illustrated. New York, 1945. John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd.

MINERAL RESOURCES

Steep Rock Iron Mines. W. Samuel. (Engineering Journal, 1945, vol. 28, Jan., pp. 4-9). An account is given of the trial borings which led to the discovery of a bed of hard hematite ore containing about 60% of iron underneath Steep Rock Lake in Toronto. The present state of the work of draining part of the lake is also described.

Ore from Iron Mountain Mine Now Used as Burden for Granite City Furnaces. (Blast Furnace and Steel Plant, 1945, vol. 33, Jan., pp. 79-80). A brief account is given of the history of the production of iron ore at Iron Mountain, Missouri. The mine was recently reopened to supply ore to blast-furnaces near St. Louis.

Titaniferous Magnetite Deposits on the Lake Sanford Area, New York. R. C. Stephenson. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1789: Mining Technology, 1945, vol. 9, Jan.). An account is given of the geology of the titaniferous magnetite deposits in the Adirondack Mountains in the State of New York.

Analyses of Pennsylvania Anthracitic Coals. (United States Bureau of Mines, 1944, Technical Paper No. 649). A comprehensive report on the anthracite fields of Pennsylvania is presented. In addition to analyses, it contains information on the situation and geology of the seams and on the mining, production, distribution and use of the coal.

Analyses of Kentucky Coals. (United States Bureau of Mines, 1944, Technical Paper No. 652). A comprehensive account of the Kentucky coalfields is given.

ORES—MINING AND TREATMENT

Ore and Coal Handling on the Lower Great Lakes. A. E. Gibson. (Steel, 1944, vol. 115, Nov. 27, pp. 95-98, Dec. 4, pp. 130-132, 166-168). The development of ore and coal handling on the Lower Great Lakes since 1844 is described. More recent developments show a substantial increase in the efficiency of unloading ore-boats and loading coal into ships.

Iron Ore Loading Dock at Port Arthur. J. M. Fleming. (Engineering Journal, 1945, vol. 28, Jan., pp. 26-32). A description is given of the high-level ore dock at Port Arthur on Lake Superior, which is being built to facilitate the loading of Great Lake steamers with iron ore from Steep Rock Lake.

Block Caving and Ore Blending. C. T. Post. (Iron Age, 1945, vol. 155, Mar. 1, pp. 50-53). Descriptions are given of the "block-caving" method of mining iron ore at the Sunrise Mine, Wyoming, the Robins-Messiter ore-bedding system and the sintering plant at Pueblo, Colorado.

Large Scale Working of Adirondack Magnetites. F. J. Oliver. (Iron Age, 1945, vol. 155, Jan. 25, pp. 50-55; Feb. 1, pp. 53-56). The Adirondack ore deposits have acquired a new importance during recent years. Mines have been extended and abandoned mines reopened. By crushing, grinding and magnetic separation it is now possible to produce a high-grade sinter from ores ranging from lean to rich. The methods and machinery applied in these processes are described, and it is shown that sinters can be produced from these ores, when the plant is working at full capacity, which will be able to compete in price and quality with Lake Superior soft ores. It is therefore expected that the Adirondack magnetites will continue to be worked after the war.

Ore and Stone Crushing Machinery. (Mining Journal, 1945, Apr. 23, pp. 49-51). Descriptions are given of some modern machines for crushing and transporting ore and stone; these include roller, disc, gyratory and jaw crushing machines.

Beneficiation of Iron Ore Grows in Importance. E. W. Davis. (Engineering and Mining Journal, 1945, vol. 146, Feb., pp. 119-122). Brief particulars are given of some of the iron-ore crushing plants in the north of New York State and on the Mesabi range, and the economic aspects are discussed with particular reference to the concentration of taconite.

Recent Developments in Iron Ore Beneficiation in the United States. T. B. Counselman. (Blast Furnace and Steel Plant, 1945, vol. 33, Jan., pp. 90-95, 156, 160, 161). Methods of beneficiating different kinds of iron ore in the United States are reviewed. The "Dorco Sizer" has been developed for dealing with minus $\frac{1}{4}$ -in. material arising from a preliminary separation treatment; this performs a "hindered settling hydraulic classification" in a multi-spigot classifier.

Iron Ore Beneficiation Assumes a Major Rôle in the Manufacture of Pig Iron. W. A. Haven. (Blast Furnace and Steel Plant, 1945, vol. 33, Jan., pp. 81-83, 89). A review is presented of the increase in iron-ore sintering plants at mines and at blast-furnaces in the United States during the last few years. In 1942 and 1943 sixteen plants with a total sintering capacity of $8\frac{1}{2}$ million tons were installed adjacent to the furnaces.

Interest in Ferro-Alloy Metals Centers on Plants. R. T. C. Rasmussen. (Engineering and Mining Journal, 1945, vol. 146, Feb., pp. 130-133). Some of the concentration plants erected in the United States during 1944 for working up ores containing chromium, cobalt, manganese, molybdenum, nickel, tungsten, and vanadium are briefly reviewed.

The Structure of German Iron Ores and Its Effect on Their Concentration. H. Kirchberg and W. Luyken. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1944, vol. 27, No. 5, pp. 53-79). A report is presented of a comprehensive investigation of the characteristics of German iron ores, with special reference to the manner in which their structure and the ratio of the iron-bearing to the slag-forming elements affect the efficiency of processes of concentration.

KTH'S New Ore-Concentration Laboratory. S. Mörtzell. (Teknisk Tidskrift, 1945, vol. 75, Jan. 13, pp. 25-31). A detailed and illustrated description is given of the laboratories recently completed for Kungliga Tekniska Hogskolan (the Royal Technical College) in Stockholm, where elaborate equipment and instruments are available for determining the properties of mineral and ores, as well as for making extensive crushing, screening, flotation and magnetic separation tests.

REFRACTORY MATERIALS

Panel Tests for Thermal Spalling of Fire-Clay Bricks Used at High Temperatures. R. A. Heindl and W. L. Pendergast. (Journal of Research of the National Bureau of Standards, 1945, vol. 34, Jan., pp. 75-96). Fifty brands of fire-clay brick, of which sixteen were of the super-duty, twenty-eight of the high-heat-duty and six of the intermediate-heat-duty classes, were tested for resistance to spalling by the standard A.S.T.M. method. The relationship between the gas pressure in the pre-heating furnace, within the range of 0.2-0.6 in. of water, to the spalling of the bricks was also investigated. The stability of volume and change in absorption resulting from reheating new specimens at 1600° C. for 5 hr. under conditions of controlled gas pressure were determined in many

cases. Although there were exceptions, spalling losses increased for a majority of brands with increase in the gas pressure of the furnace. When specimens of the high-heat-duty bricks were tested as $4\frac{1}{2}$ -in. stretchers, the spalling loss tended to be greater than when tested either as headers or as 9-in. stretchers. The tendency was for the test specimens to have greater spalling losses as the number of joints in the brick panel were increased.

The Action of Alkalies on Refractory Materials. Part XVI. F. H. Clews, H. M. Richardson and A. T. Green. (Transactions of the British Ceramic Society, 1945, vol. 44, Feb., pp. 21-24). Continuation of a series of papers (see Journ. I. and S.I., 1944, No. I., p. 117 A). Cone-deformation studies of parts of the systems $\text{Na}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ and $\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ containing up to 30% of R_2O , up to 50% of Al_2O_3 and down to 40% of SiO_2 are described. The effects of additions of 2% and 5% of Fe_2O_3 are also reported. In a number of mixtures reaction was slow, and repeated meltings with intermediate grinding and rebonding were necessary to obtain consistent results. The final temperatures of cone deformation given are in general accord with the phase diagrams of parts of these systems at present available.

Basic Brick in Open-Hearth Construction. H. M. Griffith. (Blast Furnace and Steel Plant, 1945, vol. 33, Jan., pp. 104-106). A description with numerous illustrations is given of a 180-ton open-hearth furnace at the works of the Steel Co. of Canada, Ltd., which was converted to an all-basic lining with the exception of the main roof. After 155 heats the end and side walls and the area beneath the chill-plate were in perfect condition; the port roof and slope had spalled about $2\frac{1}{2}$ in. with the exception of the first three rings of basic brick adjacent to the silica roof, which were badly worn and had to be replaced. The removal of slag presented little difficulty as it was granular in character. The experience with all-basic furnace ends has been very satisfactory.

Completes Test Run on Mullite Open-Hearth Roof. C. W. Fyfe. (American Institute of Mining and Metallurgical Engineers: Steel, 1945, vol. 116, Feb. 19, pp. 128, 164). Some experiences with mullite bricks as a roof lining for open-hearth furnaces are related. Some spalling has been encountered, but a fully-suspended arched roof is under construction, and is expected to give good service.

Heat Losses and the Insulation of Open-Hearth Furnaces and Blast Furnaces. J. M. Ferguson. (Institute of Fuel War-Time Bulletin, 1945, Apr., pp. 141-150). See Journ. I. and S.I., 1945, No. I., p. 143 A.

FUEL

(Continued from p. 1 A)

Industrial Furnaces. R. J. Sarjant. (Institute of Fuel and the National Smoke Abatement Society, Report of Joint Conference, 1945, Feb. 23, pp. 10-13). Methods of using fuel as efficiently as possible in industrial furnaces are reviewed under the following headings: (1) Coal, hand-fired; (2) mechanical stoking; (3) pulverised fuel; (4) coke; (5) gaseous fuels; (6) removal of sulphur; (7) improvement in the design of industrial furnaces; (8) the importance of air preheat; (9) smoke destruction; and (10) education.

The Measurement of Pressure Difference with U-Tube Indicators. K. Kessels. (Archiv für das Eisenhüttenwesen, 1944, vol. 18, Nov.-Dec., pp. 91-96). In order to measure rates of flow in pipe-lines, the difference

in pressure in front of and behind an orifice plate inserted in the pipe line is measured with a U-tube. Formulæ for calculating the size of orifice plates for fuel-gas lines are presented and examples of their use are given.

Coal Preparation. J. C. Mitcheson. (Journal of the Institute of Fuel, 1945, vol. 18, Apr., pp. 94-98). This paper was the first of a series presented at the Conference on the Preparation and the Utilisation of Coal held at Manchester on February 28, 1945; it constitutes a summary of the communications presented to the Committee on Coal Preparation. The general view was that all coals can be prepared free from fines, but fines must be produced in winning the coal so that, if they are not utilised, very great loss of the total heat units present in the raw coal will result; such a course would raise unnecessarily the price at which coal could be sold, and the producers would ask the consumers to design their plants so that they could take coals higher in ash and also coals carrying their fair share of natural fines. In cases where low-ash coals and coals free from fines must be used, producers would ask consumers how much extra they would be willing to pay for it.

Coal Required by the Iron and Steel Industry. H. C. Armstrong. (Journal of the Institute of Fuel, 1945, vol. 18, Apr., p. 100). This was the third paper presented at the Conference on the Preparation and the Utilisation of Coal (*see* preceding abstract). The approximate requirements of coals for gas-producers, reheating furnaces and steam boilers in the iron and steel industry are outlined.

Low-Temperature Carbonization of Alaskan Coals. W. A. Selvig, W. H. Ode and J. D. Davis. (United States Bureau of Mines, 1944, Technical Paper No. 668). As considerable and increasing quantities of petroleum products are imported into Alaska, the possibility of obtaining them from Alaskan coals has been examined. A report is presented on the results of low-temperature carbonisation tests on Alaskan coals.

Repair of Silica Coke-Oven Walls by Spray Welding. G. A. Phillipson. (Coke and Smokeless-Fuel Age, 1945, vol. 7, Mar., pp. 45-48). A detailed description is given of the equipment and technique for the cement spray welding of holes in the silica bricks of coke-oven walls. With this apparatus damaged bricks at any position along the oven can be repaired without any cooling down; in fact, the brickwork must be maintained at 1000-1100° C. to effect a successful repair. The equipment consists of an oxygen/coke-oven-gas burner carried on a cast-iron trolley, which is pushed to the required position in the oven. A mixture of dry silica cement in oxygen at 20 lb. per sq. in. is fed to the centre of the burner nozzle and coke-oven gas is supplied along the tube to the outer annulus of the nozzle. The cement container, oxygen cylinder and control valves are controlled by the operator close to the oven door. A hole approximately $3 \times 3 \times 1\frac{1}{2}$ in. takes about 20 min. to fill. The method has been used with complete success at a coke-oven battery in South Wales.

The Gasification of Bituminous Coal in Producers. P. M. K. Embling. (Journal of the Institute of Fuel, 1945, vol. 18, Apr., pp. 114-123). In order to present a clear picture of the factors promoting good thermal efficiency in the producer-gas process three different plants, all of modern design producing cold clean gas for industrial purposes, are described in detail; operating data for the three plants are compared and discussed.

Blast-Furnace Gas—Wet-Washed or Dry-Cleaned? F. X. Gilg. (Iron and Steel Engineer, 1945, vol. 22, Mar., pp. 47-52). Data on the operation and performance of four water-tube boilers fired with blast-furnace gas cleaned in different ways are presented and discussed. The boilers were operated at loads of 90,000-110,000 lb. of steam per hr. at pressures in the 200-230 lb./sq. in. range. Deposits from wet-washed blast-furnace gas, even when it was thoroughly cleaned in a mechanical or electrical precipi-

tator to 0.06 grains/cu. ft., were more difficult to remove than deposits from dry-cleaned gas. Deposits from wet-washed gas were of finer texture, and clung to burners and heating surfaces like a cement or scale. Deposits from a dry-cleaned gas did not bake on the burners and were easy to remove from heating surfaces with soot-blowers. Unless wet-washing is followed by precipitator cleaning, which reduces to the dust content down to 0.02 grain per cu. ft., and extreme care is taken to avoid by-passing or overloading the precipitator even for short periods, dry-cleaning of blast-furnace gas is to be preferred.

PRODUCTION OF IRON

(Continued from pp. 1 A-3 A)

The Blast-Furnace Skip Hoist. II. G. Fox. (Iron and Steel Engineer, 1945, vol. 22, Mar., pp. 55-59). The torque on motors driving blast-furnace skip hoists was discussed in an earlier paper (*see* Journ. I. and S.I., 1943, No. II., p. 71 A). In the present paper a new type of Ward-Leonard control is described in which voltage adjustment is employed for the lower portion of the speed range and shunt-field control for the higher speeds.

The Strength Properties of Porous Sintered Iron for Bearings. H. Unkel. (Archiv für das Eisenhüttenwesen, 1944, vol. 18, Nov.-Dec., pp. 125-130). The properties of iron bearings made by the powder-metallurgy process from powder from Swedish sponge iron were investigated. The screen analysis of the powder was 84.8% below 0.04 mm. and 15.2% of 0.04-0.075 mm. Mixtures were also prepared by adding graphite, copper, lead and tin to the iron powder. The tests were made on cylindrical specimens 21 mm. in dia. made from 100, 50 and 25 g. of powder. The effects of different pressures, sintering temperatures and sintering times on the weight, hardness, strength and oil-retaining properties of the test-pieces are shown in tables and by curves.

Phenomena in the Pressing of Metal Powders. H. Unkel. (Archiv für das Eisenhüttenwesen, 1945, vol. 18, Jan.-Feb., pp. 161-167). Tests are described in which the changes in Brinell hardness and specific gravity along the length of compacts and the effects of friction on the die walls in the powder-metallurgy process were studied using copper powder and powder made from sponge iron. A mathematical analysis of the pressure distribution in the pressing of cylindrical compacts is presented.

Powder Metallurgy. - Trent. (Journal of the Institution of Production Engineers, 1945, vol. 24, Mar., pp. 73-84). The properties of many parts made by powder metallurgy are described and the advantages and limitations of the process are reviewed.

FOUNDRY PRACTICE

(Continued from pp. 3 A-5 A)

Inoculants in Gray Iron. R. H. Smith. (Iron Age, 1945, vol. 155, Mar. 15, pp. 58-62). Tests for determining the chilling tendency of grey iron are described and different inoculants and their effect on the structure and properties of the iron are discussed.

Electric Heating in the Foundry. F. Knoops. (Giesserei, 1945, vol. 32, Mar., pp. 33-37: Giessereipraxis, 1945, vol. 66, Mar., pp. 33-37). The characteristics of electric resistance, induction and arc furnaces and

their most suitable applications in the foundry are discussed. Data on current consumption and melting rates are presented.

Progress in Malleable Iron Melting in the United States. A. J. Grindle. (Foundry, 1945, vol. 73, Mar., pp. 91, 196-198). Since 1918 the proportion of hand-fired furnaces for making malleable cast iron in the United States has decreased from 90% to 2.7%. At the present time 56% of this type of iron is produced by continuous melting. Some changes in the composition of the iron which occur in the two stages of the duplex melting process are discussed.

From Natural to Synthetic Moulding Sand Production. E. Feil. (Gieserei, 1944, vol. 31, Dec., pp. 159-165; Giessereipraxis, 1944, vol. 65, Dec., pp. 183-187). A description is given of the steps taken by a foundry to change over from natural to synthetic moulding sand. The change resulted in several economic advantages, and the quality of the castings was improved.

The Effect of Grain Shape on the Moulding Properties of Synthetic Moulding Sands. W. Davies and W. J. Rees. (Joint Meeting of the Refractories Association of Great Britain, the Institute of British Foundrymen and The Iron and Steel Institute: Refractories Journal, 1945, vol. 21, Mar., pp. 98-111). The specific surface of sand (*i.e.*, the surface area of unit weight of the grains) can be determined by an air-permeability method and that of a similarly graded set of spherical grains can be calculated. These two values are known respectively as the actual and the theoretical specific surfaces. The present authors call the ratio of these values the "coefficient of angularity"; this coefficient increases as the grain shape departs farther from the spherical. The manner the coefficient of angularity varies with the grain size depends on whether the sand is from an unconsolidated deposit or from the crushing of a consolidated deposit. The use of angular-grained sands in place of round-grained sands has several disadvantages. For sands having comparable mechanical gradings it is found that: (1) In clay-bonded mixes, the green and dry strengths for the angular sands are considerably lower than those for the rounded sands; (2) in oil-bonded mixes the tensile strengths are much lower for the angular than for the rounded sands; (3) in mixes bonded with both clay and oil, the green and tensile strengths are also much lower for the angular than for the rounded sands; (4) when the mixes are made into long cylindrical cores by squeezing, the bulk-density gradient is greater for the angular than for the rounded sands; and (5) test-pieces of angular sands do not strip so easily as those of rounded sands; their surface friability after baking increases as the angularity of the grains increases.

A Report on Some Tests on Cores. F. Roll and A. Arland. (Giesserei, 1945, vol. 32, Jan., pp. 5-10; Giessereipraxis, 1945, vol. 66, Jan., pp. 5-10). Several series of tests are described in which cores were dried for 2 hr. in streams of air, oxygen, nitrogen and carbon dioxide at different velocities, after which the compression strength was measured. The following core-binders and drying temperatures were used: (1) Linseed oil at 200° C.; (2) an emulsion at 230° C.; (3) sulphite lye at 180° C.; and (4) dextrine at 160° C. With increasing velocity of the air up to 5 l. per min. the strength of the core also increased. The strength of a linseed-oil core dried in oxygen increased rapidly as the gas velocity increased to 0.2 litre per min. and then dropped sharply. The cores dried in nitrogen and carbon dioxide had very little strength at all, as neither of these gases has any effect on the oxidation and polymerisation processes in the drying.

Mould and Core Paints and Washes, and Parting Powders. W. J. Rees. (Iron and Steel Institute, 1945, this Journal, Section I). The inception of the investigation on non-siliceous alternatives to silica flour for parting powders and mould and core paints is described. Alternatives

to silica flour for parting powders which are quite satisfactory in foundry use are indicated. The trials made with mould and core paints indicate that silica flour can be satisfactorily replaced by non-siliceous materials. Calcined ball clay or aluminous fireclay is satisfactory for small and medium steel castings; for larger castings, sillimanite, calcined or fused alumina, and zircon have given satisfactory results. The choice of the most suitable alternative depends on the particular condition of foundry practice.

Determining Pouring Systems. L. Frede. (Giesserei, 1944, vol. 31, Dec., pp. 165-167; Giessereipraxis, 1944, vol. 65, Dec., pp. 187-189). Formulæ for calculating the cross-sections of sprues, runners and gates for given casting conditions are discussed.

The Basic Principles in the Feeding of Castings. J. G. Nisbet. (Institute of British Foundrymen: Foundry Trade Journal, 1945, vol. 75, Apr. 12, pp. 293-297; Apr. 19, pp. 319-322). The principles to apply when planning the position, and the dimensions of gates and risers for ferrous and non-ferrous metal castings are explained with drawings of several examples.

New Design of Horizontal-Type Foundry Oven for Baking Cores. (Industrial Heating, 1945, vol. 12, Jan., pp. 98-103). A description is given of a core-baking oven of novel design. The overall dimensions are 52 ft. long, 13 ft. wide and 27 ft. high. The cores are loaded beneath the oven on to trays suspended from a continuous conveyor, which lifts them vertically at one end of the oven to the baking section at the top through which the conveyor makes two horizontal passes. They are thus brought into the cooling zone underneath, through which the conveyor makes a single horizontal pass. Finally, the cores come out at the unloading platform below the stove. Heating is by either gas or oil. The equipment can dry up to 50,000 lb. of cores in 8 hr.

The Manufacture of Special Heat-Resisting Cast-Iron Retorts. F. J. Bullock. (Institute of British Foundrymen: Foundry Trade Journal, 1945, vol. 75, Apr. 19, pp. 323-324). A description is given of the difficulties encountered in the casting of a retort in heat-resisting cast iron. The retort was only $1\frac{1}{8}$ in. thick, and it was to hold alcohol at 850° C. at about $1\frac{1}{2}$ lb. per sq. in. Details are given of the method eventually adopted for successful production.

Casting Cutting Tools from High-Speed Steel Scrap. J. Albin. (Iron Age, 1945, vol. 155, Mar. 1, pp. 54-57). A description is given of plant and equipment with which disabled soldiers are trained to cast cutting tools of intricate shape in high-speed steel by the "lost-wax" process. This process has been described in an earlier paper (see Journ. I. and S.I., 1944, No. I., p. 193 A).

Symposium on Continuous Casting. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1793: Metals Technology, 1945, vol. 12, Feb.). Five papers were presented at the Symposium on Continuous Casting which was held in New York on February 23, 1944. The papers were:

Continuous Casting Yesterday and Today. T. W. Lippert. Continuous casting processes for ferrous and non-ferrous metals are reviewed.

The Continuous Casting of Molten Metals—History, Requirements, Metallurgy and Economics. N. P. Goss. American patents relating to continuous casting processes are reviewed and drawings of several of the machines used are presented. The author's own process is described in detail. It is designed for casting steel in 4 × 4 in. billets and has a preforming chamber, a forming chamber and vertical

moulding plates with devices for keeping the inner surfaces of the plates lubricated.

Improvements in the Direct Rolling of Strip Metal. C. W. Hazelett. Difficulties encountered in the direct rolling of ferrous and non-ferrous metals are reported with notes on how many of them have been overcome.

The Soro Process. E. I. Valyi. A description is given of the Soro casting and rolling process. It is used to produce solid shapes in sections ranging from $\frac{1}{2}$ in. up to about 4 in. in dia. A ring is cast in a two-part centrifugal-casting metal mould designed so that a riser is cast along its inner periphery. This is removed in the next operation. The ring is then severed and one end is bent outwards so that it can enter a straightening device. The equipment required is simple and inexpensive.

The Williams Process of Casting Metals. E. R. Williams. A brief account of the Williams continuous casting process is given. This has been described previously (*see* Journ. I. and S.I., 1940, No. II., p. 10 A).

Continuous Casting. L. H. Day. (Metal Treatment, 1945, vol. 12, Spring Issue, pp. 43-48). Some machines for the continuous casting of ferrous and non-ferrous metal tubes are described; these include the Williams and the Auguste Jacquet machines.

The Immersion Thermocouple in the Grey-Iron Foundry. R. C. Tucker. (Institute of British Foundrymen: Foundry Trade Journal, 1945, vol. 75, Apr. 26, pp. 335-341). A description is given of the Schofield-Grace quick-immersion thermocouple and its application in an iron foundry. It was used with success: (a) To control the casting temperature at 1430° C. in the manufacture of Newton needle heat-exchange elements; (b) to check the casting temperature of large retorts used for making carbon disulphide; and (c) to obtain data for constructing cooling curves and determining the solidification range of alloy cast irons.

Mechanization of Gray Iron Foundries. K. Lange. (Gray Iron Founders' Society: Foundry, 1945, vol. 73, Mar., pp. 96-98, 220-228). The advantages of mechanising various processes, particularly the extensive use of conveyors, in iron foundries are pointed out, and information on the cost of such installations is given.

Conveyors in Foundries, Particularly Cupola Charging Equipment. R. Stotz. (Giesserei, 1945, vol. 32, Feb., pp. 17-26: Giessereipraxis, 1945, vol. 66, Feb., pp. 17-26). A comprehensive survey, with many drawings and illustrations, of conveyor equipment in large German foundries is presented.

A Mechanised Foundry. (Automobile Engineer, 1945, vol. 20, Feb., pp. 87-94). An illustrated description is given of the highly mechanised foundry of Humber Ltd., where a variety of automobile castings are made. Special reference is made to a fixture for assembling cylinder block-cores for insertion in the mould and to methods of controlling the raw materials and testing the castings.

PRODUCTION OF STEEL

(Continued from pp. 5 A-7 A)

Steel—A Pioneer Chicago Industry. W. Sykes. (Journal of the Western Society of Engineers, 1944, Dec., pp. 5-14). A historical account of the development of the iron and steel industries of Chicago is presented.

Deoxidation with Manganese in the Basic-Bessemer Converter. H. Wentrup and O. Reif. (*Archiv für das Eisenhüttenwesen*, 1945, vol. 18, Jan.-Feb., pp. 131-138). The theory of deoxidation with manganese and with carbon is explained. The results of tests on basic-Bessemer heats are given, and show the relation between the manganese and oxygen contents of the steel. The effect of additions of spiegel to the converter on the relationship between the slag and metal compositions and that of adding ferro-manganese to the ladle on the oxygen content of the steel are discussed. At high temperatures carbon is a more active deoxidising agent than manganese, whilst at lower temperatures manganese is the more active. There is no important difference between the oxygen contents of open-hearth and Bessemer steels when the steels compared have the same carbon content.

The Basic Principles of Deoxidation by Means of Manganese and Silicon. F. Körber and W. Oelsen. (*Iron and Steel Institute*, 1945, Translation Series, No. 213). An abridged English translation is presented of a paper which appeared originally in *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1933, vol. 15, No. 21, pp. 271-309 (*see Journ. I. and S.I.*, 1934, No. I., p. 489).

The Production of Very Clean Steel in the Basic-Bessemer Shop. J. Klärding. (*Stahl und Eisen*, 1945, vol. 65, Mar. 1, pp. 118-121). Studies of casting-pit practice were made to determine the best method of producing clean ingots of basic-Bessemer rimming steel. The surface of the runners used for bottom-pouring was coated with a paste made by mixing carbon or graphite with a clay slurry; the suspension of the carbon powder was improved by the addition of either ammonium chloride or molasses. This treatment resulted in a smoother surface on the runners after casting and cleaner ingots. The best results when bottom-pouring four ingots were achieved by using four straight runners set at right angles. Frequency curves showing the degrees of cleanness at the bottom, centre and top of ingots cast under different conditions are presented.

The Control of Tropenas-Converter Blowing by a Direct-Vision Spectroscope. S. T. Jazwinski. (*Iron and Steel Institute*, 1945, this Journal, Section I). The development of a converter flame during the blow and the appearance and disappearance of certain lines of the spectrum observed through the direct-vision spectroscope are described. No attempt was made in these preliminary investigations to measure the wave-lengths of the bands, only their relative positions being recorded. A very faint continuous spectrum appeared at the beginning of the blow and grew stronger as the flame became brighter. The most pronounced yellow band appeared when boiling began; when ejects ceased a green band, faint at first, appeared. During the carbon flame two other green bands and two red bands became visible. At times a blue band was discernible. When all bands disappeared the wind was shut off.

The real value of this lies in the possibility of controlling the converter blow without introducing the human factor, and the consequent elimination of over- and under-blown heats. The disappearance of the red, green, and yellow bands is an indication that the blow is finished and the carbon near 0.1%. If the wind is not shut off when the bands disappear, the heat becomes overblown, with consequent low carbon content, higher losses of metal due to oxidation, and excessive wear on the lining. The conclusions point to a very definite relationship between the bands in the flame spectrum and the composition of the metal in the bath. This leads directly to the application of the "electric eye" to the Tropenas converter to attempt a more rigid control of the process.

Production of Steel from Battlefield Scrap. (*Steel*, 1945, vol. 116, Mar. 19, pp. 105, 146). Some difficulties in the manufacture of low-alloy

National Emergency steels from battlefield scrap most of which is high in chromium, nickel and molybdenum are discussed. High chromium contents can be removed by a two-slag practice or by diluting the heat with either carbon-steel scrap or by using a high proportion of molten pig-iron. Up to 0.15% of copper in steel is not harmful, but when more than 0.25% is present the ingots should be cooled down before putting in the soaking pits and reheated with the least possible oxidation before rolling. The real solution to the problem of using battlefield scrap lies in proper sorting at the steelworks before charging.

Recent Metallurgical Developments in Steelmaking. H. B. Emerick. (Blast Furnace and Steel Plant, 1945, vol. 33, Jan., pp. 96-99). A number of recent papers on steelmaking problems, such as temperature measurement, segregation, deoxidation and slag control, are reviewed.

Mobile Charging Machine for Steel Furnaces. (Engineering, 1945, vol. 159, May 4, p. 346). **Charging Electric Steel and Other Furnaces.** (Iron and Coal Trades Review, 1945, vol. 150, Apr. 13, pp. 549, 551). **Charging Electrical Steel and Other Furnaces.** (Metallurgia, 1945, vol. 31, Mar., pp. 257-258). A description is given of a mobile charging unit for electric and other furnaces. It runs on three wheels, the rear one mounted on a caster which constitutes the driving and steering element. It is electrically driven, and receives its current either through a flexible cable and drum or by a trolley pole with collectors running on an overhead track.

Electric Furnace Alloy Steel Plant Expanded by A. M. Byers Company. (Industrial Heating, 1945, vol. 12, Jan., pp. 71-82, 104). A description is given of the extensions to the steel-making plant at the works of A. M. Byers Company, Pittsburgh, which consist of two 25-ton electric furnaces and three soaking-pits with auxiliary equipment.

Scrap Melting Procedure Saves Alloys. V. E. Zang. (Foundry, 1945, vol. 73, Mar., pp. 92-93, 198). Some of the results obtained during twelve months operation of 1½-ton and 3-ton acid electric furnaces working with a high proportion of scrap and turnings in the charge are presented and discussed.

Arc Furnace Regulators. R. A. Geiselman and J. E. Reilly. (Steel, 1945, vol. 116, Mar. 19, pp. 136-139, 170-172). A new form of electrical control for the motors which raise and lower the electrodes in arc furnaces is described with circuit diagrams.

An Improved System of Electric Drive for Cranes. J. A. Jackson and M. A. Whiting. (Iron and Steel Engineer, 1945, vol. 22, Mar., pp. 62-68). The characteristics of an ideal electric drive for the three motions of a steelworks' crane, *i.e.*, bridge travel, trolley travel and hoist, are set out and the control system developed by the authors to meet these requirements is described.

Review of Slag Control in 1944. W. O. Philbrook. (Industrial Heating, 1945, vol. 12, Jan., pp. 84-90, 113; Feb., pp. 262-266). The purpose of slag control and methods of carrying it out are discussed and data on the time when the first slag tests are made in American basic open-hearth practice are presented.

Laminations in Welded Steel Plates. F. L. Goldsby. (Iron Age, 1945, vol. 155, Feb. 15, pp. 66-69). The formation of pipe, blow-holes and scabs in ingots is discussed and it is shown how these form various kinds of laminations in rolled plate, some of which are harmful whilst others are not so serious as to cause the plate to be rejected.

Steel Ingots. E. Barber. (British Steelmaker, 1945, vol. 11, Jan., pp. 14-18; Feb., pp. 76-80; Mar., pp. 122-126; Apr., pp. 166-171). Some of the essential factors in sound ingot production and the principles on which they are based are discussed. Part I. deals with the theory of the cooling of steel, the advantages and disadvantages of top and bottom

pouring and feeder heads. In Parts II. and III. rimming steel ingots, cleavage planes, ingot cracks and ingot shape are discussed. In Part IV. the reasons for taper on an ingot are given and the manner in which mould coatings, pouring practice and mould bottom design affect the quality of the ingot are dealt with.

FORGING, STAMPING AND DRAWING

(Continued from pp. 8 A-9 A)

Forging Die Design. J. Mueller. (Steel Processing, 1945, vol. 31, Feb., pp. 97-99). The design of dies for forging small connecting rods is discussed.

Practical Forging of Steel. M. B. Halpenny. (American Society for Metals: Canadian Metals and Metallurgical Industries, 1945, vol. 8, Feb., pp. 20-25, 45). Recommendations on the preparation of ingots and billets for forging and on the forging technique itself are made.

Forging Propeller Hubs. L. E. Browne. (Steel, 1945, vol. 116, Mar. 19, pp. 111, 148). A description is given of a large hydraulic press and the special dies for making steel hubs with four hollow arms for variable-pitch aeroplane propellers.

Forming and Drawing Steel in Kirksite "A" Dies. C. W. Hinman. (Steel Processing, 1945, vol. 31, Feb., pp. 107-108). Some examples of light steel pressings made with "Kirksite A" dies are described and illustrated. This patented die material is a hard zinc alloy with a melting point of only 717° F. and a high compressive strength.

Carbide Mandrel Effectiveness Increased by Proper Application and Maintenance. E. Glen. (Wire and Wire Products, 1945, vol. 20, Feb., pp. 134-135, 158). Recommendations are made on the maintenance of carbide mandrels and dies for tube drawing.

Lubrication in Deep Drawing Metals. S. Spring. (Steel, 1945, vol. 116, Mar. 19, pp. 112-113, 150-154; Mar. 26, pp. 100-104, 132-144; Apr. 2, pp. 109-110, 158-170; Apr. 9, pp. 114-122). The first part of this series of articles on lubrication in deep-drawing operations explains the nature of metal surfaces and the theory of sliding friction. In the second part boundary lubrication, extreme-pressure lubrication and wear are dealt with. In the third part the factors promoting the welding of work and tools and the building-up of metal on the tools are discussed. Finally, consideration is given to the composition and properties of drawing lubricants.

Phosphate Coatings as Applied to Wire Drawing. V. D. Smith. (Wire and Wire Products, 1945, vol. 20, Feb., pp. 121-123). The advantages of applying a phosphate coating to wire before drawing it are discussed. The coating has a good capacity for holding oil and die wear is considerably reduced.

ROLLING-MILL PRACTICE

(Continued from pp. 9 A-10 A)

Rolling Mills and Practice in 1944, and Present Trends in Design and Operation. G. G. Beard. (Blast Furnace and Steel Plant, 1945, vol. 33, Jan., pp. 100-103). There has been little advancement in the design of rolling mills owing to war-time conditions. One new feature was the development of a rolling process for producing alloy steel sheets partially

shaped and tapered to conform with the contour of aeroplane propeller blades. New mills of the four-high type for rolling wide alloy steel strip to thin gauges are expected to have work rolls of smaller diameter in the post-war period.

Electrical Developments in the Steel and Non-Ferrous Industries. G. E. Stoltz. (Blast Furnace and Steel Plant, 1945, vol. 33, Jan., pp. 107-108). Recent developments in electrical equipment for steel production are reviewed. The advantages of twin-motor drives for rolling mills are pointed out. A new type of control for electric furnaces incorporates rotating regulators that match the current input per electrode against its voltage across the arc.

Additives in Oil for the Steel Plant. C. E. Pritchard. (Iron and Steel Engineer, 1945, vol. 22, Mar., pp. 75-82). Addition agents for lubricating oils which are intended to prevent oxidation of the oil, and the corrosion and wear of the metal being lubricated are discussed. A lubrication test in which an upper ball is spun on three lower balls at extremely high pressure is described.

Replace Seamless Tube Mill in Ten Weeks. (Steel, 1945, vol. 116, Apr. 9, pp. 125-128). A description is given of the new Mannesmann tube mill for producing steel tubes from 2 $\frac{7}{8}$ to 7 $\frac{1}{2}$ in. in dia. at the works of the Pittsburgh Steel Company.

HEAT TREATMENT

(Continued from pp. 10 A-12 A)

Some Metallurgical Principles for the Efficient Heat-Treatment of Steel. A. Dubé and S. L. Gertsman. (Transactions of the Canadian Institute of Mining and Metallurgy, 1945, vol. 48, pp. 165-183). An account is given of the developments brought about in the last fifteen years by metallurgical research on the heat-treatment of steels; their practical aspects are specially emphasised. Methods of representing the phase-change during austenitising and the sub-critical transformation of austenite are described and the importance of time-temperature-transformation charts for the planning of heat-treatment cycles is shown. Retained austenite and stresses developed by quenching are discussed.

Some Aspects of the Hardening and Hardenability of Steel. (Metal Treatment, 1945, vol. 12, Spring Issue, pp. 23-28, 22). A dilatometric method of determining the hardening temperature for steel is described. Grossmann's method of measuring hardenability from end-quench test data and the use of hardenability factors in steel specifications are discussed.

Salt Baths and Their Hazards. E. G. West. (Industrial Fire Brigades' Association of Great Britain: Metal Treatment, 1945, vol. 12, Spring Issue, pp. 49-55). The fire risk associated with salt baths, especially those used for the heat-treatment of aluminium, is discussed. Care must also be exercised in steel heat-treatment shops. For instance, work should never be transferred from a high-temperature cyanide bath to a low-temperature nitrate bath because of the danger of explosion.

The Principles and Practice of Lithium Heat-Treating Atmospheres. Part III. Carbon Restoration. C. E. Thomas. (Industrial Heating, 1945, vol. 12, Jan., pp. 42-46). Conclusion of a series of articles (*see* Journ. I. and S.I., 1945, No. I., p. 153 A.). It is shown that decarburised parts can be recarburised in a lithiated atmosphere consisting of eleven parts of air to one of propane and that the lithium process can be used for descaling.

Prepared Atmospheres Used in Furnaces for Heat Treating at Chrysler Tank Arsenal. (Industrial Heating, 1945, vol. 12, Jan., pp. 19-38, 104). An illustrated description is given of the extensive equipment at the works of the Chrysler Corporation for heat-treating various parts of tank drive mechanism. Radiant tube furnaces with protective atmospheres are principally employed.

Continuous Heat Treatment. H. W. Smith, jun. (Iron Age, 1945, vol. 155, Mar. 8, pp. 58-63). Illustrated descriptions are given of compact heat-treatment units for the continuous heating of bars and tubes. These consist of cylindrical chambers with cup-shaped burner recesses on the inside. The bars or tubes are supported on water-cooled rolls to prevent sagging as they pass through the chamber. A very high rate of heat transfer is obtained. One furnace, for example, is 7 in. in inside dia. and 13 in. long; it will take steel tubing up to 3½ in. in dia. which is fed through at rates of from 2 to 5 ft. per min. depending on the size.

Fundamental Principles and Applications of Induction Heating. Part VI. Internal Hardening and Assembly Processes. Part VII. Miscellaneous Applications. (Sheet Metal Industries, 1945, vol. 21, Mar., pp. 489-493; Apr., pp. 651-657, 681; May, pp., 837-843). Continuation of a series of articles (*see* Journ. I. and S.I., 1945, No. I., p. 153 A). Induction-hardening apparatus for hardening the internal surfaces of hollow bodies and inductor coils for heating parts for brazing are described and illustrated in Part VI. and a variety of applications of induction heating such as the "flowing" of tin on electrolytic tinplate, drying paint and lacquer, heating the ends of bombs for spinning and heating bolt blanks for upsetting are dealt with in Part VII.

Induction Heating of Internal Surfaces in the Automotive Industry. H. E. Somes. (Society of Automotive Engineers: Steel Processing, 1945, vol. 31, Feb., pp. 90-96, 130). A detailed description is given of a machine for the induction hardening of the internal surfaces of hubs and other automobile parts.

Megacycle Induction Heating. V. W. Sherman. (Electrochemical Society: Steel, 1945, vol. 116, Mar. 12, pp. 116, 156-167). *See* Journ. I. and S.I., 1945, No. I., p. 104 A).

Rotating Hearth Furnaces. A. C. Kramer. (Industrial Heating, 1945, vol. 12, Feb., pp. 248-252). An illustrated description is given of a heat-treating plant consisting of two oil-fired rotary-hearth furnaces 10 ft. in dia. and quenching tanks. The advantages of this type of plant are discussed.

Cold Treatment in Gage Stabilization. C. T. Post. (Iron Age, 1945, vol. 155, Mar. 15, pp. 52-54). Particulars are given of cold treatments at down to -120° F. developed by J. A. Harrington for stabilising gauges. The procedure after the usual heating and quenching was to cool the part to -120° F. and then temper at 275° F. and repeat this six times. A single chilling treatment for 36 hr. followed by tempering did not achieve such complete transformation of the austenite. A stability test for gauges developed by the Bureau of Standards is described.

WELDING AND CUTTING

(Continued from pp. 12 A-15 A)

Low-Temperature Welding in Steel Plant Maintenance. R. D. Wasserman. (Iron and Steel Engineer, 1945, vol. 22, Mar., pp. 70-74). The theory of welding ferrous and non-ferrous metals with alloys having melting points well below that of the parent metal is explained and several applications for steelworks' maintenance are described.

Welding Light-Gage Steel. R. V. Anderson. (Steel, 1945, vol. 116, Mar. 12, pp. 104-105, 150). Illustrated descriptions are given of jigs which facilitate rapid welding in the mass production of parts made of light gage steel sheet.

Unionmelt Welded Anchor Chain. (Iron Age, 1945, vol. 155, Mar. 8, pp. 64-67). The manufacture of stud-link anchor chain to United States Navy specifications in Unionmelt automatic welding machines is described and illustrated. The Unionmelt process has been described previously (see Journ. I. and S.I., 1939, No. I., p. 284 A).

Flash Welding SAE-4130 Steel. W. W. Ackerman and W. Pestrak. (Steel, 1945, vol. 116, Apr. 9, pp. 104-105, 140-146). See p. 12 A.

The Effect and the Purpose of the Coating Materials on Welding Electrodes. F. Rapatz and W. Hummitzsch. (Stahl und Eisen, 1945, vol. 65, Mar. 1, pp. 109-118; Mar. 15, pp. 141-146). The fundamentals of the electric welding process were studied. The amount of electrode metal melted in a given time depends on the product of the welding current and voltage. Substances in the coating which can be easily ionised reduce the resistance of the air gap to the arc and reduce the melting rate and *vice versa*. Electrodes coated with acid minerals melt more rapidly than those with alkaline minerals. The former require more manganese in the coating and the latter are more economical in alloying elements. Acid mineral coatings cause the metal to be transferred in long thin droplets; such electrodes can be used with either direct or alternating current. Basic coatings on the other hand cause the metal to be transferred in separate droplets; these electrodes must be connected to the positive pole of a direct current supply. The melting rate is about the same whether the coating material reactions are exothermic or endothermic. The least number of inclusions and the lowest nitrogen and oxygen contents are found in welds made with basic-coated electrodes.

The Relation between the Hydrogen Content of Weld Metal and Its Oxygen Content. L. Reeve. (Iron and Steel Institute, 1945, this Journal, Section I). Considerable study of the welding of high-tensile steels in recent years has indicated that cracking may occur in the hardened zones of the base plate immediately adjacent to the weld. It has been shown by several investigators that certain types of weld metal, including highly oxidised ferritic types and austenitic weld metal, are largely immune from this cracking tendency. It has also been shown more recently that this may be related to the diffusible hydrogen content of the weld metal.

The main purpose of the investigation reported in this paper is to determine the relationship between the FeO content of weld metal and its total and diffusible hydrogen content.

It is shown experimentally that the total hydrogen content is slightly reduced, whilst the diffusible hydrogen content is considerably reduced, when the FeO content in the weld is increased. An attempt is made to explain these results theoretically on the basis of the data reported by Chipman (Transactions of the American Institute of Mining and Metallurgical Engineers, 1937, vol. 125, pp. 331-345) for the system Fe-FeO-H₂-H₂O at temperatures above the melting point of iron, and from a discussion of the probable behaviour of the hydrogen in solution after solidification of the weld. Lepp's paper on the same subject (Journ. I. and S.I., 1940, No. I., p. 329 P) is also discussed and is shown to lead to similar results for liquid iron.

The influence of micro-cavities and of inclusions is discussed, with particular reference to the influence of the active FeO content of the inclusions. It is confirmed that the baking of an electrode at 350° C. will reduce the hydrogen content in the resultant weld, but attention is drawn to the simultaneous change in the oxygen content which may occur.

Controlled Atmosphere Furnace Brazing. A. K. Phillippi. (Pressed Metal Institute: Steel Processing, 1945, vol. 31, Feb., pp. 111-114; Industrial Heating, 1945, vol. 12, Feb., pp. 222-232). Several roller-hearth and linked-belt continuous furnaces for the furnace-brazing of small parts in protective atmospheres are described and illustrated.

Some Effects of Surface Decarburization on Flame-Cutting Characteristics of High Carbon Bar Stock. J. K. Magor. (Canadian Metals and Metallurgical Industries, 1945, vol. 8, Feb., pp. 26-28). In the oxy-acetylene cutting of $2\frac{1}{4}$ in. \times $\frac{5}{8}$ in. bars of 0.75% carbon steel the slag adhered strongly to the under surface and made machine flame-cutting exceedingly difficult. Methods of preventing this were investigated. Burner tips of various sizes and different oxygen pressures were tried. The best results were obtained with a cutting orifice 0.029 in. in dia., an oxygen pressure of 65-70 lb./sq. in. for cutting, the minimum amount of preheating and as fast a cutting rate as possible without "flame drag." Even under these conditions bars behaved differently. An examination of the microstructures showed that when the surface of a bar was completely decarburised to a depth of more than 0.006 in. the slag adhered strongly to the under side whilst perfectly clean cuts were obtained when there was only a little or no decarburisation. By "spark-testing" on the as-rolled surface of the bars those unsuitable for cutting could be rapidly identified and separated.

MACHINING

Tipped High-Speed Steel Widely Used. F. J. Oliver. (Iron Age, 1945, vol. 155, Jan. 18, pp. 58-61, 137-140). A report is presented on an extensive survey of machine-shop practice in the United States the object being to discover the extent to which high-speed steel tools are used in the tipped form and in the solid form, as well as to obtain details of the brazing, welding and heat-treatment procedures.

Striking Improvements in Machinability Claimed for Lead Steels. (Steel, 1945, vol. 116, Feb. 19, pp. 136-139). The results of machining tests on lead steels and steels without lead are presented and compared. These show that cutting speeds on lead-bearing steels can be increased by 24-35% without altering the other machining conditions.

Machining of Ferrous and Non-Ferrous Materials. J. W. Donaldson. (Metal Treatment, 1945, vol. 12, Spring Issue, pp. 3-12). In recent years machining practice has undergone a change in the development of improved cutting materials and new alloys of the free-machining type have been introduced. A summary of the present position as regards cutting tools and a brief review of recent British and American investigations on machinability from the metallurgical standpoint are presented.

Evaluation of the Finish of a Metal Surface by a Replica Method. H. K. Herschman. (Journal of Research of the National Bureau of Standards, 1945, vol. 34, Jan., pp. 25-31). **Replica Method for Evaluating Finish of a Metal Surface.** H. K. Herschman. (Mechanical Engineering, 1945, vol. 67, Feb., pp. 119-122). A new method for evaluating surface roughness involving the use of rapidly produced plastic replicas of variable transparency is described. Evaluations of surface finish made on fine specimens which differed significantly in degrees of finish were correlated with profile values of these surfaces determined by (a) the profilometer method, and (b) the microscope on cross sections. The data show that the replica method is particularly suitable for evaluating surfaces having a high degree of finish.

Salvaging High-Speed Steel Scrap. E. Simons. (Steel, 1945, vol. 116, Feb. 19, pp. 140, 166). Economical methods of making machining tools and using up high-speed steel scrap are described.

PROPERTIES AND TESTS

(Continued from pp. 18 A-22 A)

The Shape of a Materials' Reactions to Force.—Part I. A. C. Vivian. (Metallurgia, 1945, vol. 31, Mar., pp. 225-229). The suggestion is made that there should be one suitable stress-strain curve which would be a complete statement of all the elementary mechanical properties of a material, whilst certain other properties—hardness, fatigue endurance, notch-toughness and damping capacity—are all derivatives or compounds of the same. In the electrical analogy, current, voltage, resistance, &c., are elemental and are compounded in heating effect, electromagnetic effect, &c. The one true curve is the graph obtained on testing at room temperatures at a rate of loading which fractures the specimen in a minute or two. The features of such a curve are pointed out and obstacles which have hitherto blocked the road to a better understanding of the above concept are dealt with.

The Technical Mechanism of Plastic Deformation. E. Siebel. (Archiv für das Eisenhüttenwesen, 1944, vol. 18, July-Aug., pp. 13-22). The relation between stress and flow in metals is discussed on the basis of the mechanism of deformation of crystallites of parallelopiped shape. The stress conditions at the initiation of plastic flow and when the completely plastic region has been reached are particularly important; these can be determined when there is a definite yield point. In industrial processes of deformation elastic changes may be neglected and the volume may be considered constant. Representing deformation by the natural logarithm of the ratio of dimensions before and after, the sum of the strains in the three principal directions will be zero and the work of deformation per unit volume will be a product of the deformation and the deformation resistance. Certain losses of energy have to be taken into account and the means of dealing with these are illustrated by numerical examples.

Influence of Tempering Temperatures upon the Strength of Heat-Treated Steels. D. W. Rudorff. (Metallurgia, 1945, vol. 31, Mar., pp. 237-240). An abridged English translation is presented of a paper by A. Krisch which appeared in Stahl und Eisen, 1944, vol. 64, Feb. 17, pp. 105-110 (see Journ. I. and S.I., 1944, No. II., p. 111 A).

The Development of a Single-Blow Impact Test for Cast Iron. A. B. Everest, J. W. Grant and H. Morrogh. (Iron and Steel Institute, 1945, this Journal, Section I). Applications of modern high-duty cast iron in the Services and in engineering practice generally often call for a measure of shock resistance, and the need has been felt for some time past for a simple test to evaluate this quality. A sub-committee of the Technical Advisory Panel to the Directors for Iron Castings, Ministry of Supply, was therefore set up to collaborate with the British Cast Iron Research Association in reviewing the work previously carried out in this field and to explore the possibilities of standardising a suitable test. After reviewing previous work it was decided that the Izod form of test offered the best possibilities and had the further advantage that suitable machines were widely available. The small test-piece, standard for steel, however, is useless for cast iron, owing to its relatively low impact value. Tests were put in hand, therefore, using larger test-pieces, with and without notches

or grooves. Selected forms of test-piece were distributed to various investigators and the consistency of the results obtained on standard grades of cast iron was studied. Whilst a satisfactory range of values has been established, unfortunately discrepancies between different machines and the variation in results due to the normal heterogeneity of cast iron have led to a scatter of results which up to the present does not justify final standardisation. A recommended procedure, however, has been evolved and is now in regular use by a number of investigators for a period of time prior to further consideration with a view to its possible ultimate standardisation. Peculiarities of the test on cast iron exist, such as the double-blow effect, whereby the broken part of the specimen shows frequently two or more impressions of the knife-edge. This phenomenon has been studied in detail and the mechanism of the double-blow effect finally established by a high-speed photographic record of the test in progress. Other variables have also been studied with a view to their elimination as possible disturbing factors in the test.

Impact Resistance vs. Hardness of Aircraft Low Alloy Steels. J. M. Thompson, jun. (Iron Age, 1945, vol. 155, Mar. 8, pp. 72-74). Rockwell hardness tests and impact tests were performed on two chromium-molybdenum steels and a chromium-nickel-molybdenum steel. The specimens were heat-treated in various ways, some by quenching in oil at 70-150° F. and tempering, and others by quenching in a salt bath at 500° F. and tempering. The hardness was found to be inversely proportional to the impact strength. The salt-quenched specimens had a greater resistance to impact than the oil-quenched specimens.

Work Hardening and Notch Sensitivity of High Strength Steels. L. M. Pevzner. (Iron and Steel Institute, 1945, Translation Series, No. 226). An English translation is presented of a paper which appeared in *Izvestia Akademii Nauk S.S.S.R.*, 1944, No. 12, pp. 864-869. Data on the relation between the tensile and impact strengths of a high-tensile chromium-nickel-molybdenum steel after various heat-treatments are presented and discussed.

Notch Fractures. (British Steelmaker, 1945, vol. 11, Apr., pp. 156-163). The value of notched-bar impact tests as a measure of the properties of steel is discussed.

Metallurgical Aspects of the Failure of Colliery Haulage and Winding Gear. J. H. Woodhead. (National Association of Colliery Managers: Iron and Coal Trades Review, 1945, vol. 150, May 4, pp. 659-664, 672). The main causes of failure, as revealed by the examination of over 400 samples of broken or defective colliery haulage and winding gear and by associated research work, are discussed. A large proportion of the failures were caused by using material of poor quality, particularly in the case of wrought iron. The failures of mild steel gear were due mostly to the use of unsuitable material, such as free-cutting steel. The blacksmith's welding of wrought iron gear should be done with great care as a large number of the failures were caused by defective welds. Forging should always be followed by normalising.

Changes in Materials Subjected to Fatigue Stresses. A. Karius, E. Gerold and E. H. Schulz. (Archiv für das Eisenhüttenwesen, 1944, vol. 18, Nov.-Dec., pp. 113-124). The changes in the damping capacity and elastic modulus of six steels, brass and aluminium caused by fatigue stresses were investigated. The steels comprised two 0.06% carbon steels, two chromium-copper steels, a molybdenum steel and a 25/18 chromium-nickel steel. The changes occurring in different polycrystalline materials as a result of repeated stresses appear to be of a similar nature and to develop in the same manner in relation to time. At the beginning of the fatigue test there is a marked increase in damping and a corresponding

drop in the elastic modulus due mainly to cold-deformation and the internal stresses which are set up; as the strength of the material increases the rates of change in the above properties gradually decrease. A second drop in the elastic modulus occurs shortly before failure in the fatigue test. The magnitude of the initial changes in the damping and elastic modulus depend upon the volume of the test-piece, whereas the changes which occur just before fracture are not dependent on the volume. In fatigue tests on notched bars the stresses are concentrated in a small volume of the material and the damping and elastic modulus continue to change rapidly throughout the test. It was found that cracks occurred in the notch surface early in the test; at stresses below the fatigue strength these penetrated rapidly to a depth of up to 0.1 mm. but did not become deeper as the test proceeded. Although the damping is very sensitive to changes in fatigue stress, it is not suitable for setting up damage curves.

The Effect of Recovery Periods in Fatigue Testing. A. Karius, E. Gerold and E. H. Schulz. (*Archiv für das Eisenhüttenwesen*, 1945, vol. 18, Jan.-Feb., pp. 155-159). The recovery of fatigue-test specimens which takes place on interrupting the test was studied by observing the changes in damping and elastic modulus of specimens of a high-tensile steel. In the first part of the test internal stresses are set up which do not lead to cracks; these stresses are reduced by a period of rest at room temperature and disappear entirely if the temperature is raised to 150° C. The recovery is greatest if the test is stopped after applying sufficient stress reversals to complete the cold deformation. This number amounts to 10-20% of the number of reversals to fracture in an uninterrupted test. The recovery appears to have no connection with strain-ageing. A rest period shortly before fracture when the damping and elastic modulus have changed owing to the occurrence of macroscopic cracks has no beneficial effect. The material suffers intrinsic damage through the gradual exhaustion of the capacity of the individual crystals to deform and this cannot be made good by interrupting the test.

The Flexural Fatigue Strength of Forgings of Alloy Steel with Longitudinal and Transverse Grain Flow. G. von Rössing. (*Iron and Steel Institute*, 1945, Translation Series, No. 225). An English translation is presented of a paper which appeared in *Archiv für das Eisenhüttenwesen*, 1942, vol. 18, Mar., pp. 407-412. (*See Journ. I. and S.I.*, 1943, No. I., p. 213 A).

Determinations of the Effect of Liquids on the Strength, Particularly of Glass and of Hardened Steel. C. Benedicks and G. Ruben. (*Jernkontorets Annaler*, 1945, vol. 129, No. 2, pp. 37-96). (In Swedish). It is well known that glass can be cut more easily under water and that surrounding metal specimens with water when carrying out tensile, bend and fatigue tests reduces the values obtained. The literature on these phenomena is reviewed and accounts of new investigations are given. Tensile tests on bolts from Trollhättan power station which had failed showed that fracture occurred at scratches which had just been wetted. The fatigue strength of 13%-chromium was reduced 38-57% when the specimen was kept in a stream of water. The transverse strength of glass was reduced 38% by water, 23% by ethylalcohol and 21% by glycerine. The resistance to bending of specimens 2 mm. in dia. of a hardened carbon steel was measured in a Chevenard machine with photographic recording apparatus; this resistance was reduced 14% by water and 5% by 1% sodium hydroxide whilst an increase of 15% was noted when 10% sodium hydroxide was used.

The Effect of Liquids on the Occurrence of Cracks and on the Attraction between Two Flat Surfaces. C. Benedicks and P. Sederholm. (*Jernkontorets Annaler*, 1945, vol. 129, No. 2, pp. 107-117). (In Swedish).

Calculations are made respecting the surface tension and negative pressure of liquids and the combined effects of the negative pressure of a liquid and the cohesive forces of a solid body are discussed. The practical significance of these effects with regard to cracks in metals is discussed. Both strengthening and weakening influences are at work; when a crack is short and wide the former influence is at a minimum and the weakening effect dominates. When the crack is deeper and narrower the strengthening effect is greater, but the actual behaviour of the material depends upon its special properties and those of the liquid. When the crack has developed to complete fracture the liquid exerts a strengthening effect only.

A Contribution to the Study of Ordinary Carbon and Medium Manganese Steel Rails. J. S. Vatchagandhy and G. P. Contractor. (Transactions of the Mining, Geological and Metallurgical Institute of India, 1944, vol. 39, Sept., pp. 161-191). A comparative study was made of ordinary carbon and medium manganese steel rails. Whilst the tensile and yield point strengths of both types are essentially the same at 49 and 28 tons/sq. in., respectively, the elongation and reduction of area of the manganese steel rail are about 17% and 51% higher respectively. The manganese steel rail has a better wear-resistance and a greater tendency to work-harden than the carbon steel rail. The fatigue limits of both types of rail are essentially the same. Metallographically, the medium manganese rail with its sorbito-pearlite structure is decidedly superior to the plain carbon rail which has ordinary lamellar pearlite with a network of ferrite; inclusions in the former are not as numerous as in the latter. The rate of cooling of the manganese steel rail on the hot beds is approximately 20° C./min. faster than that of the carbon steel rail. In the cooling of flat-bottomed carbon steel rails curvature arises in a single sweep with the head concave, whereas the manganese steel rail forms a double bend with a slight "hump" in the centre; the reasons for this difference in behaviour are given.

Some Recent Developments in Engineering Materials. A. Black. (Mechanical Engineering, 1945, vol. 67, Feb., pp. 101-108; Mar., pp. 190-198). This review of war-time developments in metals and alloys covers the properties and applications of the National Emergency steels, high-strength cast irons and cast steels, leaded steels, graphitic steels and steels containing boron as well as the properties which can be developed by heat-treatment, cold-treatment and by impregnation with silicon.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 22 A-23 A)

The Preparation of Cemented Carbides for Micro-Examination. D. H. Shute. (Metal Treatment, 1945, vol. 12, Spring Issue, pp. 13-18, 37). Several methods of polishing metallographic specimens of the cemented-carbide hard metals and the technique of the etching and micro-examination are described.

The Determination of Lattice Constants* from Diffuse Interference Lines. H. Neerfeld. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1944, vol. 27, No. 6, pp. 81-89). When determining lattice constants from X-ray back-reflection diagrams it often happens that two lines overlap, especially when plastic deformation has occurred. A technique is described by which a correct determination of the lattice constant can be made in such cases.

Radiographic Specifications and Standards for Naval Materials. C. L. Frear. (Transactions of the American Foundrymen's Association, 1945, vol. 52, June, pp. 1078-1110). The United States Navy Department requires radiographic examination of steel castings used for high-pressure steam lines and for other important service in ships. Particulars are given of the equipment necessary for these examinations and of the "radiographic standards" which have been drawn up as a guide to the interpretation of radiographs and to deciding whether repairs to a defect are necessary.

The Intermediate Phase Structures in Steel and Their Origin. H.-J. Wiester. (Archiv für das Eisenhüttenwesen, 1944, vol. 18, Nov.-Dec., pp. 97-112). A report is presented of a comprehensive investigation of the effect of carbon and of alloying elements on the transformation of austenite, with special reference to the intermediate phase structures. The steels examined contained 0.1-1.6% of carbon, 0-1.5% of chromium, 0-1.1% of molybdenum and 0-4.5% of nickel. The structures obtained are illustrated by 59 micrographs.

Contribution to the Knowledge of the Transformation Phenomena in Chromium and Manganese Steels. E. Houdremont, W. Koch and H.-J. Wiester. (Archiv für das Eisenhüttenwesen, 1945, vol. 18, Jan.-Feb., pp. 147-154). The transformation of steels containing up to 1.0% of carbon, up to 3.5% of manganese and up to 24% of chromium was studied by chemical and X-ray analyses of the electrolytically isolated carbides. The carbides which form in the intermediate phases and on tempering after the transformation to martensite in both chromium and manganese steels are very much lower in chromium and manganese respectively than are those formed in the pearlite phase; the amount of alloying element present in the carbides decreases with decreasing transformation temperature. The amounts of alloying element present in the carbides in the intermediate and in the tempered martensite phases are increased by annealing in the temperature range of the pearlite phase up to the equilibrium quantities. The observations made provide an explanation for the narrowing of the temperature range of the pearlite phase in alloy steels. The application of these results to the problem of the resistance of welds to high-pressure hydrogen is discussed.

Ar'' in Chromium Steels. E. P. Klier and A. R. Troiano. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1799: Metals Technology, 1945, vol. 12, Feb.). The influence of chromium contents between 1% and 15% in low-manganese steels on the Ar'' point was studied using the quench-temper method of A. B. Greninger and A. R. Troiano (see Journ. I. and S.I., 1940, No. I., p. 50 A). The steels were divided into four groups with carbon contents of 0.4%, 0.7%, 1.0% and 1.3% respectively. On plotting the Ar'' temperatures against the chromium contents for each of the groups, four almost parallel straight lines were obtained; the Ar'' point was lowered by about 23° C. for every increase of 1% of chromium. The microstructures obtained are discussed.

ANALYSIS

Spot Tests for the Detection of Alloying Elements in Steel. B. S. Evans and D. G. Higgs. (Analyst, 1945, vol. 70, Mar., pp. 75-82). A system of spot tests is described for the detection of nickel, chromium, manganese, molybdenum, tungsten, aluminium, copper, lead, titanium, cobalt, selenium and vanadium in alloy steels. Most of the tests are sensitive down to at least 0.1%.

Method for the Photometric Determination of Cobalt in Tool and High-Speed Steels in the Presence of Iron and Other Alloying Elements. G. Bogatzki. (Iron and Steel Institute, 1945, Translation Series, No. 221). An English translation of a paper which appeared in *Archiv für das Eisenhüttenwesen*, 1943, vol. 17, Nov.-Dec., pp. 125-126 is presented. See *Journ. I. and S.I.*, 1945, No. I., p. 68 A.

Colorimetric Determination of Phosphorus in Steel and Cast Iron. M. Herzog. (Chemist Analyst, 1944, vol. 33, Feb., pp. 4-7). The Hague and Bright method of determining phosphorus in steel and cast iron which uses the phospho-molybdenum blue colour has already been described (see *Journ. I. and S.I.*, 1941, No. II., p. 144 A). In this paper some modifications are described which result in a saving of time and reduce the amount of reagents required.

The Determination of Phosphorus in Steel Containing Titanium. J. L. West. (Analyst, 1945, vol. 70, Mar., pp. 82-86). A method of preventing the interference of titanium when determining phosphorus in steel is described. Titanium has an inhibiting effect on the precipitation of phosphorus as phospho-molybdate, but this can be prevented by adding hydrofluoric acid followed by boric acid to counteract the effect of any excess hydrofluoric acid.

Rapid Methods for Determining Phosphorus and Sulphur in Iron and Steel. O. Rydberg. (*Jernkontorets Annaler*, 1945, No. 1, p. 32). (In Swedish). In the method for the determination of phosphorus the phosphorus is precipitated as ammonium phospho-molybdate. The solution is made acid and potassium-thiocyanate and stannous chloride are added. The reaction between the molybdenum and the thiocyanate turns the solution red the intensity of which depends on the amount of molybdenum, which in turn depends on the amount of phosphorus precipitated. The solution is then compared colorimetrically with a solution from steel containing a known amount of phosphorus.

To determine the sulphur a 1-g. sample is burnt at 1200-1300° C. in a stream of oxygen and the products of combustion are passed into distilled water. The electrical conductivity, which varies with the amount of dissolved sulphur dioxide, is measured with a Wheatstone bridge, and the amount of sulphur is obtained from a calibration curve. The analysis can be made in 2 or 3 min. and the result is accurate within about 0.0005%.

Sulphur in Cast Iron. J. T. Wilson and J. Bennett. (*Foundry*, 1945, vol. 73, Feb., pp. 81, 218). Methods of determining sulphur in cast iron are reviewed and a combustion process based on using neutral potassium iodide-iodate as the absorbent, starch as the indicator and titrating the iodine released by the sulphur dioxide with sodium thiosulphate is described.

A Volumetric Micro-Analytical Process for the Determination of Silicon in Unalloyed Steels or Steels Alloyed with Silicon Only. J. Mika. (*Archiv für das Eisenhüttenwesen*, 1944, vol. 18, July-Aug., pp. 7-12). A volumetric method for determining silicon in 0.1-g. samples of steel is described. It is based on the precipitation of silicon as pyridine-silicomolybdate. The method is suitable for routine analyses and does not call for a very high degree of care and skill. It takes less time and costs less than the usual gravimetric method and the results are just as accurate.

A Rapid Volumetric Method for the Determination of Silicon in Iron and Steel. F. Kordon. (*Archiv für das Eisenhüttenwesen*, 1945, vol. 18, Jan.-Feb., pp. 139-146). The rapid method of determining silicon in iron and steel which is described is based on the fact that under certain conditions silicon will combine with fluorine ions in the presence of potassium salts (such as potassium chloride) to form potassium fluosilicate which can be titrated with caustic alkali. The results of numerous tests

are given which establish the conditions for the solution and precipitation of the potassium fluosilicate. The interference of alloying elements was studied. Iron, manganese, chromium, nickel, molybdenum, vanadium, tungsten, cobalt and copper have no effect, whilst aluminium, titanium, zirconium and tantalum interfere because they form fluorine complexes which are difficult to dissolve. There was good agreement between the results of gravimetric determinations and those obtained by the method described. With plain carbon steels the determination takes about 15 min., whilst about 30 min. are required for cast iron and alloy steels.

The Determination of Nitrogen in Ferro-Alloys and Other Materials by Direct Nesslerisation without Distillation. W. C. Newell. (Iron and Steel Institute, 1945, this Journal, Section I). The direct method, without distillation, for the colorimetric determination of nitrogen is applied to the analysis of ferro-alloys by the addition of stabilising colloids to the Nessler-ammonia coloration. Its application to metallurgical analysis is shown to be extensive, resulting in a far simpler and speedier method for the determination of nitrogen in steel and other alloys.

Use of Potassium Dichromate Method in Determining Iron Content of Pickle Acids. E. G. Porst. (Journal of The American Ceramic Society, 1945, vol. 28, Feb. 1, pp. 62-64). A volumetric method for the determination of iron in acid pickling solutions which employs potassium dichromate as the standard solution is described. The indicator used is diphenylamine. This method is superior to the potassium permanganate one, because the solution has greater stability during storage and is prepared and standardised more easily. The procedure and results are discussed.

Polarography. G. W. Birdsall. (Steel, 1945, vol. 116, Mar. 5, pp. 122-123, 162-172). The principles, applications, advantages and limitations of the polarographic method of analysis are discussed.

A Micro-Spectrographic Method for the Quantitative Analysis of Steel Segregates. J. Convey and J. H. Oldfield. (Iron and Steel Institute, 1945, this Journal, Section I). Steel-segregate analysis by the spot-spark method (Journ. I. and S.I., 1941, No. II., p. 183 P) gave higher average values for all elements on the segregates than those on the normal metal. The elements manganese, molybdenum and vanadium showed the greater percentage increase. Careful examination of the segregate analyses revealed variations in element content within a single segregate. An attempt was made to determine the graduation in composition across a segregate by a careful linear location of the actual points tested. Although the results were good it was recognised that a technique was required whereby a continuous record of the variation in content across a segregate could be determined. A method was developed whereby the sample could be guided under a stationary upper electrode, while the photographic plate on which the spectrogram is recorded moved downwards across the camera aperture of the spectrograph. Spectrograms were obtained on which the spectral lines varied in density over their length according to local changes in the composition of the specimen along the path of the spark. By means of Meccano parts a system of transmission was designed and built. The speeds of transmission of the sample and the photographic plate were adjusted to give spectrograms of a density similar to that obtained by the spot-spark method.

Tests were made on several well-worked Ni-Cr-Mo steel bars of small section, and the results corroborated the content homogeneity of the bars. Spark traverses of the order of 7 mm. in length were made across various segregates in different types of steel and the results calibrated against standard steels. Such exposures produced spectrograms whereon the spectral lines were 5.4 cm. long. The clean definition and uniformity of

the spectral lines throughout their lengths is a good proof of the continuity and smooth motion of the mechanical functioning of the transverse system. The effect of sparking on the steel samples is a crater very uniform in width (0.4 mm.) and depth (0.02 mm.) throughout its length (7 mm. approx.).

To obtain a quantitative analysis of the steels for carbon a higher steady-state potential of the spark gap was required. This was produced by blowing a small blast of dried air across the spark gap (pressure, $\frac{1}{2}$ in. of water). The method was standardised and tested. Analyses of segregates were identical with those obtained with the spot-spark and traverse-spark techniques without air blast. Variations in the macrostructures of segregates were found to agree with the content curves obtained *via* a traverse on the sample. Carbon content showed a slight decrease across the segregate in Ni-Cr-Mo alloy steels.

A Method for the Spectrographic Analysis of Low-Alloy Steel. R. Rynninger. (*Jernkontorets Annaler*, 1945, vol. 129, No. 1, pp. 1-31). (In Swedish). A spark-excitation method for the spectrographic analysis of low-alloy steels is described in detail. The results obtained for each element are accurate within 2.5-3.0% and this small error is due mainly to imperfections in the photographic plate. Suitable lines for the determination of silicon, manganese, chromium, nickel, molybdenum and copper for the amounts usually present in chromium-nickel-molybdenum steels are given. The possibility of using the method for routine analyses in the control of production is discussed.

Quantitative Spectrographical Analysis. D. S. Beard. (*Scientific Journal of the Royal College of Science*, 1944, vol. 14, pp. 124-139). Factors affecting the accuracy of quantitative spectrographical analysis are discussed. The properties of photographic emulsion are examined and this shows that the results of photographic methods of measuring line intensities depend entirely on empirical data. The rotating-sector and the microphotometer methods of measuring line intensities are explained. The choice of line-pairs and calibration curves, methods of excitation and sources of error are discussed.

REFRACTORY MATERIALS

(Continued from pp. 28 A-29 A)

The Reversible Thermal Expansion and Other Properties of Some Calcium Ferrous Silicates. G. R. Rigby, G. H. B. Lovell and A. T. Green. (Transactions of the British Ceramic Society, 1945, vol. 44, Mar., pp. 37-52). The preparation of a number of compositions in the CaO-FeO-SiO_2 ternary system is described. These include the minerals fayalite (2FeO.SiO_2) and three compositions in the metasilicate series of solid solutions between wollastonite (CaO.SiO_2) and FeO.SiO_2 . The specimens were examined in thin sections and the optical properties are described. Other data determined on these minerals were the reversible thermal expansions between 100° and 1000°C. , the density, and the rates of reduction and oxidation in hydrogen and oxygen respectively. The importance of lime ferrous silicates in slags, sinters and refractory materials is also discussed.

Refractory Concrete for Furnace Construction. G. T. Haddock. (Metals and Alloys, 1945, vol. 21, Feb., pp. 395-400; Mar., pp. 714-718). The properties and methods of preparing and using refractory concrete are reviewed. In this paper the term "refractory concrete" covers all concrete suitable for use at temperatures between 500° and 1400°F. Crushed firebricks form a good aggregate for making refractory concrete; the grading is important, as the proportion of fines must be much higher than that in structural concrete. Several applications, such as cooling pits for forgings, covers for annealing furnaces and the repair of blast-furnace linings, are described.

Permeable Refractories in Furnace Construction. R. H. Anderson, D. C. Gunn and A. L. Roberts. (Institute of Fuel: Iron and Coal Trades Review, 1945, vol. 150, June 15, pp. 889-891). The theory of the use of permeable refractories in furnaces through which the hot gases pass instead of leaving directly by a flue has been explained in an earlier paper (*see* Journ. I. and S. I., 1945, No. I., p. 40 A). In the present paper experience gained with a bogie-hearth furnace 12 ft. 6 in. long, 10 ft. wide and 5 ft. 6 in. high used for annealing 12-20 ton charges of steel castings at 920°C. is discussed. The anticipated trouble with the clogging of the permeable refractories by dust in the furnace atmosphere did not occur. A rapid rate of heating and a low fuel consumption were obtained.

Basic Bricks. (Iron and Steel, 1945, vol. 18, Apr., pp. 110-115, 119; May, pp. 147-149, 159). A detailed and fully illustrated description is given of the plant and process at West Hartlepool by which magnesia is produced on a large scale from the sea. This plant produces 800 tons of magnesia per week requiring 1000 tons of dolomite and 65,000,000 gal. of sea-water. The manufacture of stabilised dolomite bricks and cements in England is also described.

FOUNDRY PRACTICE

(Continued from pp. 31 A-34 A)

Automobile Castings. (Iron and Steel, 1945, vol. 18, May, pp. 150-155). The production of alloy cast iron at the foundry of the Midland Motor Cylinder Co., Ltd., has already been described (*see* Journ. I. and

S.I., 1945, No. I., p. 94 A). In the present paper a detailed account of the foundry equipment and layout, with special reference to sand preparation, is given.

Thermal Lag in Heat-Treatment Operations, with Particular Reference to the Annealing of Malleable Cast Iron. A. E. Peace. (Institute of British Foundrymen: Foundry Trade Journal, 1945, vol. 76, May 24, pp. 67-72). The transfer of heat by conduction, convection and radiation is discussed, with data on the thermal conductivity of metals, non-metallic solids and gases. The theory is then applied to show the extent of the thermal lag in the annealing of malleable iron castings in boxes with and without inert packing material. The design of annealing pots and furnaces to secure the best results is considered.

The Rate of Spheroidization and the Physical Properties of Pearlitic Malleable Iron after Isothermal Quenching. W. H. Bruckner and J. Hino. (Transactions of the American Foundrymen's Association, 1945, vol. 52, June, pp. 1189-1214). The possibilities of reducing the time required for malleablising white cast iron were investigated. In the first stage of the treatment the iron is heated to about 1700° F., held for sufficient time to decompose all massive cementite into nodular graphite, and then cooled in air. In the second stage the pearlite resulting from the transformation of the residual austenite is spheroidised by holding at 1280° C. for 30-40 hr. The effect of cooling (a) in the furnace, (b) in air, (c) in lead at 100° F., (d) in lead at 800° F., and (e) in a lead alloy at 600° F. at the end of the first stage of the treatment was examined. With the exception of the furnace-cooled series, the spheroidising of all the specimens was substantially complete after 5 hr. at 1280° F., but good ductility was not obtained until after 10 hr. at 1280° F.

Studies on Bore Cracks in Flanged Fittings. J. A. Duma and S. W. Brinson. (Transactions of the American Foundrymen's Association, 1945, vol. 52, June, pp. 1217-1250). An investigation of the factors affecting the occurrence of cracks in the bore of steel pipe fittings opposite flanges was carried out by making numerous castings of a 2-ft. length of pipe 7 in. in dia. with wall $\frac{1}{2}$ in. thick and a flange at each end 15 in. in dia. \times 1 in. thick. The dimensions and positions of the gates and risers were changed and chills and pads were resorted to. The formation of cracks was prevented by inserting two sets of chills, one round each end of the core, consisting of small square bars $\frac{3}{8} \times \frac{3}{8} \times 5$ in. long spaced $\frac{1}{2}$ in. apart. As the cracks were shallow, another method was to cast pads on the inside of the pipe at each end; the cracks then occurred in the pads, which were subsequently machined off.

Mold Atmosphere Control. H. W. Dietert, R. L. Doelman and R. W. Bennett. (Transactions of the American Foundrymen's Association, 1945, vol. 52, June, pp. 1053-1077). It is shown that a protective gas envelope can be obtained by the injection of reducing or inert gases into the moulding sand or core of a mould before or during the pouring of the metal, or by mixing chemical liquids or solids with the sand, or by using a special facing material. In this way the surface of castings can be improved, thus reducing the cleaning costs. Rammed sand specimens were prepared $1\frac{1}{8}$ in. in dia. \times 2 in. long with a $\frac{1}{4}$ -in. hole $1\frac{1}{2}$ in. deep at one end, and pins of 0.23% carbon steel were inserted in the holes. These were put in a small electric furnace and raised to temperatures in the 1600-2900° F. range and held for 12 min. The interior of the furnace was charged with one of many different gases. The moulds were subsequently broken open, and the effects of the gas were studied by examining both the sand and the steel pin.

Fourth Progress Report on Investigation of Physical Properties of Steel Foundry Sands at Elevated Temperatures. D. C. Williams. (Transactions of the American Foundrymen's Association, 1945, vol. 52, June, pp. 979-

1036). Work done on the high-temperature testing of foundry sands at Cornell University, Ithaca, New York, including the results of co-operative tests conducted at three other laboratories to determine the hot compressive strength of test specimens of moulding sands is recorded. The report deals mainly with the steps taken to standardise the testing equipment and procedure so that results in the different laboratories would be comparable. There are three appendices to the report. In the first, H. W. Dietert makes recommendations on the operation of the dilatometer in the hot-testing of sands. In the second, H. Ries presents data on the effect of changes in the rate of loading. In the third, the effect of various types of rammer support on the properties of rammed sand specimens is discussed.

Notes on Oil-Sand Practice in the Ordinary Foundry. W. Y. Buchanan. (Proceedings of the Institute of British Foundrymen, 1943-44, vol. 37, pp. B 63-B 75). Recommendations are made with regard to the equipment and methods for storing, drying and mixing oil sands in jobbing foundries.

Report of the Subcommittee on Sintering Test, Foundry Sand Research Committee, 1943-1944. (Transactions of the American Foundrymen's Association, 1945, vol. 52, June, pp. 1311-1316). See Journ. I. and S.I., 1944, No. II., p. 73 A.

Thermosetting Plastic Core Binders for Ferrous and Non-Ferrous Metals. W. C. Morgan. (Transactions of the American Foundrymen's Association, 1945, vol. 52, June, pp. 1317-1324). Tests are reported in which the properties of cores prepared with linseed oil and with plastic binders are compared. Plastic binders are particularly useful for aluminium and magnesium castings, and mixtures have now been prepared for iron and steel castings. The time required for baking the cores and for removing them after casting is very much reduced. Less gas is evolved from a core bonded with a plastic material, and the gas is reducing in nature rather than oxidising.

The Use of Gypsum Cements in Pattern and Model Making. E. H. Schleede. (Transactions of the American Foundrymen's Association, 1945, vol. 52, June, pp. 1271-1285). See Journ. I. and S.I., 1945, No. I., p. 97 A.

A Study of Molding Methods for Sound Castings. F. G. Sefing. (Transactions of the American Foundrymen's Association, 1945, June, vol. 52, pp. 1126-1136). Some of the principles to apply in making sound castings are discussed, and practical examples are described and illustrated. The following recommendations are made: (1) Pouring gates should be designed so that clean metal enters the mould quietly and rapidly; (2) gates with rectangular cross-sections are better than round or square sections; (3) the gates and risers should be designed so as to promote controlled directional solidification; (4) adequate venting of the mould cavity prevents back pressure and reduces the absorption of gas by the metal; and (5) where a wide variety of castings is made, records of the successful moulding practice should be kept; a good record is a photograph of the casting as poured showing the gates, risers and chills with the dimensions inserted.

Technical Control in the Jobbing Foundry. R. D. Cheyne. (Institute of British Foundrymen: Foundry Trade Journal, 1945, vol. 76, May 17, pp. 47-50). Difficulties encountered in the casting of a 3-ton bedplate, long hydraulic spindles and valve boxes and the methods adopted to overcome them are described.

Drying and Preheating of Foundry Ladles. C. E. Bales and F. McCarthy. (Transactions of the American Foundrymen's Association, 1945, vol. 52, June, pp. 1286-1292). See Journ. I. and S.I., 1945, No. I., p. 122 A.

Costs in a Jobbing Foundry. H. E. E. Holladay. (Institute of British Foundrymen: Foundry Trade Journal, 1945, vol. 76, May 10, pp. 25-30).

Details are given of methods of costing which were successfully introduced at foundries of three different types, one where large castings with heavy labour charges on each were made, the second, at a repetition foundry producing large numbers of castings for municipalities, and the third a mixed jobbing and light repetition foundry.

New Methods of Occupational Disease Control in the Foundry. W. A. Cook. (Transactions of the American Foundrymen's Association, 1945, vol. 52, June, pp. 1357-1364). Recommendations are made on methods of preserving the health of foundry workers. These are concerned with (1) preventing stray X-ray radiation; (2) the danger arising from the fumes of styrene, carbon tetrachloride, cadmium and tellurium; (3) the control of dust; and (4) general ventilation.

Toxicity of Fumes Generated in the Operation of Electric Furnaces. J. W. Fehnel. (Transactions of the American Foundrymen's Association, 1945, vol. 52, June, pp. 1365-1371). Data are presented on the composition of the fumes around and above electric furnaces used for making silicon alloys, ferro-manganese, ferro-vanadium and alloys containing tungsten and cobalt.

The Application of Local Exhaust Ventilation to Electric Melting Furnaces. J. M. Kane. (Transactions of the American Foundrymen's Association, 1945, vol. 52, June, pp. 1351-1356). Ventilation systems suitable for electric arc furnaces in steel foundries are described and illustrated. Exhaust hoods for the charging doors, pouring spout and electrodes have been devised which do not interfere with the movement of the swinging roof, and charging and the tilting of the furnace.

PRODUCTION OF STEEL

(Continued from pp. 34 A-37 A)

Canadian Steel Industry. D. B. McCoy. (Canadian Metals and Metallurgical Industries, 1945, vol. 8, Mar., pp. 38-39, 42). The growth of the Canadian iron and steel industry is reviewed, with special reference to the expansion during the war years 1940-1945.

A Pattern for Western Steel Production. H. F. Bain. (United States Bureau of Mines, Mar., 1945, Information Circular No. 7315). The economic development of the Western States of the United States and, in particular, the relation of the iron and steel industry to that development, are reviewed and discussed. The prospects of the new steel-producing plants being able to work at or near full capacity in the post-war years are considered.

Kaiser Builds at Fontana. T. J. Ess. (Iron and Steel Engineer, 1945, vol. 22, Apr., pp. 22-K-42-K). A comprehensive and profusely illustrated description is given of the new integrated iron, steel and rolling-mill plant at Fontana, California.

Production and Characteristics of Killed Bessemer Steel. E. C. Wright. (American Society for Metals: Iron Age, 1945, vol. 155, Mar. 22, pp. 59-61). The development of a Bessemer practice for making killed steel suitable for manufacturing seamless tubes is described. The metal was blown in the converter until the carbon flame dropped; the converter was then turned down and sufficient molten pig-iron put in to bring the carbon up to 0.15%. It was teemed into the ladle and the standard additions of ferro-manganese, ferro-silicon and aluminium were made. A practice was developed by which fully-killed Bessemer steel with up to 0.50% of carbon could be produced.

Dephosphorized Bessemer Steel Used for Many Products. G. Yocum. (American Society for Metals: Iron Age, 1945, vol. 155, Mar. 22, pp. 61-64). A practice for producing Bessemer steel containing only 0.03-0.05% of phosphorus is described and its properties and applications are discussed.

Reversing Regenerative Furnaces. J. R. Green and J. P. Vollrath. (Iron and Steel Engineer, 1945, vol. 22, Apr., pp. 67-76). The measurement of temperature in regenerator chambers is described and four methods of controlling the reversal of gas flow are discussed. These methods are: (1) *Automatic time reversal* in which the chamber conditions are balanced by firing each end of the furnace for fixed lengths of time. (2) *Temperature-difference reversal systems* in which the chamber conditions are balanced irrespective of the temperature level at which they are operated; this method is applied principally to batch furnaces. (3) *Floating maximum temperature reversal system* which is designed to initiate the reversal from the temperature conditions in the hot ends of the checker chambers during their heating cycle. (4) *Preheat drop reversal system*; this is based on initiating the reversal from a predetermined permissible drop in the preheating temperature.

Slag Control. N. H. Bacon. (Swansea and District Metallurgical Society: Iron and Steel, 1945, vol. 18, Mar., pp. 86-90; Apr., pp. 124-126). A detailed description is given of a method of slag control which has been successfully applied to 80-ton basic open-hearth furnaces. Average figures over 21 weeks indicate that the following advantages have accrued: (1) The time from charging to tapping was reduced from 12 to 11 hr.; (2) the metallic yield was increased from 94.7% to 95.0%; and (3) the total lime per cast was reduced from 7.95 to 7.45 tons. As the compositions of the slag and metal show very little variation during the last 30 min. of the melting period analyses can be made by the rapid methods of D. Manterfield so that the amounts of the lime and oxide additions can be calculated by the time the bath is ready for them. The value of the data and curves presented lies in the fact that they enable the approximate analysis and volume of the tapping slag and the degree of dephosphorisation which will be attained in the steel covered by this slag to be predetermined.

The Application of Statistical Methods to the Development and Quality Control of High Tensile Steel. C. M. Mottley. (Journal of the American Society of Naval Engineers, 1945, vol. 57, Feb., pp. 21-55). In 1942 a new manganese-titanium steel for high tensile steel ship plates was developed in the United States as a substitute for vanadium steel. Test data on the chemical composition and properties of the new steel accumulated rapidly and the Bureau of Ships organised a "quality control unit" which employed modern statistical methods to analyse the mass of data and develop means of controlling the production. An account of this organisation and its methods is given.

Valves for Modern Open-Hearth Furnaces. A. G. Arend. (British Steelmaker, 1945, vol. 11, May, pp. 214-217). The advantages and disadvantages of different designs of reversing valves for open-hearth furnaces are discussed. A type which is advocated is one without a water seal, but which utilises water for cooling; in this design the drop-type gas and air inlet-valves are combined with sluice or gate-valves in the feeding ducts. The sluice and inlet-valves ensure safe and reliable alternating control, as they are interconnected by ropes.

The Modern Ingot Buggy with Amplidyne Control. R. E. Marrs. (Blast Furnace and Steel Plant, 1945, vol. 33, Mar., pp. 355-359). Electrically-driven cars fitted with tilting mechanism and delivery roller drive for conveying ingots from the soaking pits to the rolling mill are being more frequently used. A detailed description is given of the control

circuits for a car capable of carrying a 35-ton ingot. The safety devices on it include a photo-electric signal system and an automatic siren.

Melting and Evaporating Metals in a Vacuum. W. J. Kroll. (Electrochemical Society, Apr., 1945, Preprint No. 6). Factors involved in the melting and evaporation of metals at reduced pressures, and those resulting from lower temperatures, are discussed. The effects of the hydrostatic pressure of the molten metal, of metal vapour pressure, of residual gas pressure, and of residual gas pressure on the actual temperature and pressure at the point of evaporation are shown to be very important. Surface films are also controlling factors. Evaporation-condensation upward and downward from solid and from liquid states are considered. Purification of metals and recovery of a metal from an alloy by vacuum distillation are discussed. Data on evaporation temperatures for various conditions at reduced pressures are tabulated.

The Constitution of Some Basic Open-Hearth Slags. B. Mason. (Jernkontorets Annaler, 1945, vol. 129, No. 4, pp. 171-184). (In Swedish). This is a Swedish translation of a paper which appeared originally in Journ. I. and S.I., 1944, No. II., p. 69 p-80 p.

Prevention of Flakes in Steel Forging Billets. P. S. Kingsley. (Metal Progress, 1945, vol. 47, Apr., pp. 699-704). The literature on the causes of flakes in steel is reviewed. The author's theory is that flakes are internal ruptures caused by a combination of the following stresses: (1) Contraction stress set up by the temperature gradient from the outside to the inside of the piece; (2) stress caused by the pressure of hydrogen; (3) stress caused by phase changes during cooling; and (4) residual stress after hot-working. If the cooling and reheating cycle for rolled billets is controlled so that these four types of stress do not occur at the same time the internal ruptures can be prevented. The way in which this is done at the works of the Follansbee Steel Corporation is described. A gas-fired furnace 345 ft. long is used. A number of cars travelling on a track form the floor to the furnace. The billets are carefully stacked with spaces between them on the cars which are pushed into the heating zone, then the soaking zone, and finally the cooling zone. Minimum times for different billets in the soaking zone have been established, but these times can be exceeded as the temperature is under the A_c1 point. The trouble of flakes in the billets has been practically eliminated since the introduction of this system.

FORGING, STAMPING, AND DRAWING

(Continued from p. 37 A)

Production of 8 In. Shells at Christy Park Works of National Tube Company. A. B. Salkeld. (Steel Processing, 1945, vol. 31, Mar., pp. 164-167, 194). An illustrated description is given of the sequence of processes by which steel billets $10\frac{1}{2}$ in. in dia. and $13\frac{1}{8}$ in. long are pierced and extended to $17\frac{1}{4}$ in. long and then drawn down to 8.6 in. in dia. and 36 in. long to make 8-in. shells.

Quality Control in a Forge Shop. J. Mueller. (Steel Processing, 1945, vol. 31, Mar., pp. 168-172). Recommendations on methods of controlling the quality of forgings are made with examples of useful process and inspection record cards.

Induction Heating for Forging. H. A. Strickland, jun. (Metals and Alloys, 1945, vol. 21, Mar., pp. 719-723). The advantages and disadvantages of applying induction heating to the heating of forgings are

discussed and data on the cost of the equipment and process are presented.

Considerations in Casting and Coining Malleable Iron. H. W. Streeter. (Transactions of the American Foundrymen's Association, 1945, vol. 52, June, pp. 1146-1150). Tests are described in which the effect of different pressing conditions on malleable iron rings and bars was studied. The iron contained 2.41% of carbon and 1.18% of silicon. All the rings were $2\frac{1}{2}$ in. in outside dia. with a 1-in. hole; half of them were approximately $\frac{1}{2}$ in. thick and the remainder were approximately 1 in. thick. The patterns were made 0.505 in. thick for the $\frac{1}{2}$ -in. rings but the malleable castings were 0.517 in. thick instead of 0.500 in. as expected. The $\frac{1}{2}$ -in. rings were coined by pressing between flat plates with die stops 0.485 in. and 0.452 in. thick; on pressing at 300 tons per sq. in. to the 0.485 in. stops the average thickness of 18 rings after releasing was 0.493 in. After pressing at 400 tons per sq. in. to the 0.452 in. stops the average thickness was 0.462 in. Tensile, elongation and hardness tests were made on solid square bars before and after coining; the results proved that malleable iron work-hardens under pressure.

Notes about Some Steel Cartridge Cases Made in Germany. (Metal Progress, 1945, vol. 47, Mar., pp. 491-496). Detailed descriptions are given of German cartridge cases from 2 in. in dia. up to 210-mm. mortar shells drawn from steel blanks.

Further Comments on Scotland's Wire Practices. A. P. Newhall. (Wire and Wire Products, 1945, vol. 20, Mar., pp. 193-194). The wire-drawing practice at the works of the Speedwell Wire Co., Ltd., Coatbridge, is described.

HEAT TREATMENT

(Continued from pp. 38 A-39 A)

Atmosphere Applications—Equipment, Methods and Process Cycles. F. E. Harris. (Metal Progress, 1945, vol. 47, Apr., pp. 713-723). Equipment for supplying special atmospheres to heat-treatment furnaces is described and methods of controlling the gas flow and calculations of the time required to purge a furnace are explained. Some practical examples of the supply of atmospheres suitable for carburizing, carburizing and diffusing the carbon, replacing the carbon lost by decarburized bars, and for oxide coatings are given.

Metallurgical Control of Shaved Aircraft Gears. R. E. Liebendorfer. (Iron Age, 1945, vol. 155, Apr. 19, pp. 56-61). The "shaving" of gear teeth is the machining before heat-treatment to dimensions which allow for the distortion which will take place (see Journ. I. and S.I., 1945, No. I., p. 23 A). In this paper details are given of the procedure adopted by the Wright Aeronautical Corporation to control the heat-treatment of shaved gears so as to prevent decarburisation.

Isothermal Treatment of Hot Ingots and Forgings. I. P. Lipilin. (Iron and Steel Institute, 1945, Translation Series, No. 216). This is an English translation of a paper which appeared in *Katshestvennaia Stal*, 1936, No. 10, pp. 12-22. It describes experiments on the effects of different heat-treatments for cast and for forged bars of high-speed steel, tool steel and die steel. The austenite in cast specimens of two tungsten high-speed steels transformed more slowly than specimens from large forgings and the latter transformed more slowly than those from rolled bars. On the basis of the experimental data heat-treatment schedules were devised which saved considerable time because the bars could be put

in the heat-treatment furnace after partial cooling instead of allowing them to cool to room temperature.

Heat Treating Stainless Steels. (Steel, 1945, vol. 116, Apr. 16, pp. 112-120, 160-162; Apr. 23, pp. 88-89, 128-136). Data on the effect of a variety of heat-treatments on the properties of three types of corrosion-resisting steel are presented and discussed. The three types are: (1) straight chromium hardenable steels containing from 11.5% to 18% of chromium; (2) straight chromium non-hardenable ferritic steels containing from 14% to 27% of chromium; and (3) chromium-nickel non-hardenable austenitic steels.

Heat Treating 18-8 Stainless in Salt Baths. K. Whitcomb. (Iron Age, 1945, vol. 155, Apr. 26, pp. 48-52). A method of annealing stainless steel exhaust manifolds to remove the stresses set up by welding is described. Tests were made with a number of molten salt baths at about 1750° F. and pure sodium carbonate was found to be entirely satisfactory and much superior to barium chloride baths.

An Annealing Department Laid Out for Efficiency. R. K. Weyant. (Wire and Wire Products, 1945, vol. 20, Apr., pp. 265-269, 303). An illustrated description is given of the additions and improvements which have been made to the annealing department of the Wilson Steel and Wire Company, Chicago. The additions include a vertical and movable furnace cover which can be lowered on to any one of three loading bases 74 in. in dia., as well as equipment for producing a protective atmosphere for the bright-annealing of coils of wire.

Spheroidizing Cycles Standardised. H. L. Hopkins. (Iron Age, 1945, vol. 155, Apr. 19, pp. 72-75). A description is given of the tests which were made to establish standardised annealing and spheroidizing cycles to produce the optimum properties in coils of 0.3-0.4%-carbon steel wire for subsequent manufacture into bolts.

Heat Treating Armor Plate at Ford Rouge Plant. (Industrial Heating, 1945, vol. 12, Mar., pp. 383-400). An illustrated description is given of one of the five production lines for the heat-treatment of armour plate at one of the plants of the Ford Motor Company. It consists of a gas-fired radiant-tube furnace 200 ft. long with a roller hearth to take plates up to 5 ft. wide. The plates are held at about 1650° F. for 1 to 3 hr. depending on the thickness of the plate. To prevent distortion the plates are quenched between the platens of a 2500-ton hydraulic press; the surface of the press dies is covered with metal pads 2 in. in dia. each one drilled with 6 holes through which water is sprayed at 40 lb. per sq. in. Plates up to 18 ft. long can be quenched in the press. The plates are then tempered at 800° to 1200° F. in another gas-fired roller-hearth furnace after which they are shot-blasted to remove scale. They then pass to the torch-cutting and inspection departments.

Heat Treatment of Broaches Requires Specialized Equipment and Technique. (Industrial Heating, 1945, vol. 12, Mar., pp. 410-418). The equipment and processes at the works of the Colonial Broach Company, Detroit, for the heat-treatment of high-speed steel and carbon steel broaches up to 9 ft. long are described and illustrated.

Modification by Heat-Treatment of Cast Structures and Properties. H. T. Angus. (Proceedings of the Instituté of British Foundrymen, 1943-44, vol. 37, pp. A 122-A 131). The effects of various heat-treatments, without hot or cold work, on the microstructure and properties of a hyper-eutectoid high-silicon cast steel and a medium-carbon cast steel, both made in acid electric furnaces by the duplex process of continuous coating were investigated. There is quite a wide range of heat-treatment for the medium-carbon steel within which good mechanical properties are obtainable and, provided adequate soaking time is allowed before quenching,

previous normalising is not necessary. The maximum ductility is obtained in the hyper-eutectoid steel by a spheroidising anneal at 780–800° C. for 3 or 4 hr. followed by cooling at a rate not exceeding 40° C. per hr.

The Control of Composition and Heat-Treatment in 0.25-C 1.5-Mn Steel Castings. T. W. Ruffle. (Proceedings of the Institute of British Foundrymen, 1943–44, vol. 37, pp. A 110–A 114). Tests on the effect of different heat-treatments on the properties of castings made from electric-furnace steel containing carbon 0.25%, manganese 1.5% and silicon 0.2–0.32% are described and discussed. It was found advantageous to replace the simple normalising treatment by one consisting of holding for 4 hr. at 900–920° C., quenching in water down to about 300° C., cooling in air down to about 100° C. and tempering for 3 hr. at 550–600° C.

Hardening and Shrink Fitting. (Steel, 1945, vol. 116, Apr. 30, pp. 92–93, 128–130). Induction hardening and quenching equipment is described with which bulldozer track rollers made of two hardened steel rings shrunk on to a cast-iron hub could be hardened and assembled at the rate of 15 per hr.

Sub-Zero Treatment of Steel Increases Hardness and Stability. C. M. Parker. (Machinist, 1945, vol. 89, June 2, pp. 274–276). A concise explanation of the changes in atomic structure, constituents and volume which occur in the heat-treatment of steel is presented; it also covers the effect of sub-zero treatment in increasing the hardness and stability.

Sub-Zero Treatment. (Automobile Engineer, 1945, vol. 35, May, pp. 199–202). Heat-treatment cycles for various classes of steels are discussed, and the results of tests by the General Motors Corporation with their standard treatment and five other cycles incorporating cooling down to –110° F. on a tungsten-molybdenum-chromium high-speed steel are given. An increase in the tool life was obtained by the cold treatment in each case.

Induction Heating—A History of Its Development. F. T. Chesnut. (Iron Age, 1945, vol. 155, Mar. 22, pp. 46–53). A historical account of the application of induction heating to the melting and heat-treatment of metals from E. F. Northrup's laboratory furnace of 1916 to the present day is given.

High Frequency Heating in Production Engineering. A. L. Simmons. (Institution of Production Engineers: Australasian Engineer, 1945, vol. 44, Feb. 7, pp. 35–44). The theory of dielectric and induction heating is explained with examples of their applications, and the methods of producing the necessary high-frequency current are described.

Induction Heating of Moving Magnetic Strip. R. M. Baker. (Electrical Engineering, 1945, vol. 64, Apr., pp. 184–189). The general problem of heating iron or steel strip by induction is analysed so as to arrive at equations for power-factor efficiency and density of heating under all conditions. Certain general curves are shown to illustrate the limitations of strip thickness, frequency and density of heating.

WELDING AND CUTTING

(Continued from pp. 39 A–41 A)

Building-Up and Hard Surfacing by Welding. W. Andrews. (Proceedings of the Institution of Mechanical Engineers, 1945, vol. 152, No. 1, pp. 1–4). The author describes the process of using fusion welding for renewing worn or corroded parts, and points out that it can form part of the original design for many structures. The characteristics of the various welding processes are considered.

Hard Surfacing by Welding. M. Riddihough. (Transactions of the Institute of Welding, 1945, vol. 8, May, pp. 58-62). Advantages which were gained in some of the first applications of hard-surfacing by welding are referred to, and the welding rods and electrodes now available for this purpose are discussed in four groups, namely, alloy steels with up to 20% and with more than 20% of alloying elements, non-ferrous alloys, and tungsten carbides. Recommendations for the appropriate heat-treatment are made.

Influence of Sulphur and Phosphorus on Weldability of Mild Steel. L. Reeve. (Transactions of the Institute of Welding, 1945, vol. 8, May, pp. 80-88). To ascertain the maximum permissible amount of sulphur in electrodes for welding mild steel experiments were carried out by: (a) Treating coated electrodes with chemicals to increase the sulphur content; (b) incorporating known quantities of powdered ferrous sulphide in the coatings of experimental electrodes; and (c) welding high-sulphur steels with electrodes containing normal amounts of sulphur. The sulphur limit is lower the higher the carbon content of the parent metal. The sulphur limit decreases as the electrodes depart further from the "soft" type, or, more strictly, as they become more de-oxidised. Details are given of a steel angle containing 0.068% of sulphur which cracked on welding with a highly deoxidised electrode. Electrodes from a single batch of core wire can be made to deposit weld metals of entirely different analyses and degrees of de-oxidation by altering the flux coatings. The effects of sulphur on the porosity of the weld metal, the relation between the diffusible hydrogen content and the "sulphur-sensitivity" and the influence of manganese on sulphur-cracking are discussed. The effect of phosphorus was investigated; in no case, even in weld metal containing up to 0.13% of phosphorus, has cracking of the weld metal been encountered in restrained joints.

Weldability—Hot-Rolled vs. Quenched and Tempered Constructional Steels. S. A. Herres. (Welding Journal, 1945, vol. 24, Mar., pp. 129-S-152-S). A definition of weldability is proposed and procedures for evaluating and specifying the weldability of structural steels are discussed. Published data, including the results of tests at Watertown Arsenal Laboratory, are surveyed so as to illustrate the properties obtainable in hot-rolled and in quenched and tempered structural steels, and to demonstrate how some properties are impaired by certain welding procedures.

The Welding and Fabrication of Canadian Light Armour. F. J. McMulkin. (Engineering Journal, 1945, vol. 28, Mar., pp. 141-147). The development of a satisfactory welding technique for the welding of armour plate up to 17 mm. thick at a Canadian steelworks is described.

Welded Construction of Blast Furnaces. B. E. Tau. (Blast Furnace and Steel Plant, 1945, vol. 33, Mar., pp. 343-349, 369-370). Welding specifications are given and the welding and erection techniques described for the construction of blast-furnaces.

Welding Various Metal Combinations with the Electric Arc. O. M. White. (Metallurgia, 1945, vol. 31, Apr., pp. 299-300). Techniques are described for welding brass to steel, high-manganese steel to low-carbon steel, and cast iron to steel.

Spot Welding of Alumized Steel. H. W. Brown. (Iron Age, 1945, vol. 155, Apr. 26, pp. 56-62). An investigation of the conditions necessary to produce good spot welds in aluminium-coated low-carbon steel sheet is described. The sheets tested were 0.0375 in. thick with a coating 0.0013-0.0020 in. thick of an aluminium alloy containing about 8.5% of silicon and 0.25% of magnesium. Data are presented on the effects of the electrode-tip shape and pressure, and of changes in the strength and duration of the welding current on the strength of the welds and the life of the electrodes.

A Preliminary Investigation of the Constitution of Mild-Steel Arc-Weld Deposits. H. A. Sloman, T. E. Rooney and T. H. Schofield. (Iron and Steel Institute, 1945, this Journal, Section I). The oxygen, hydrogen and nitrogen contents of mild-steel weld deposits laid down under certain standard conditions, and also the form in which the oxygen is present, have been determined. Deposits from six different electrodes were found to differ appreciably in their contents of the gaseous elements. Observations connecting these differences with the compositions of the electrode coatings have been made. A knowledge of the distribution of the oxygen, coupled with chemical analysis, has made it possible to determine the amounts of silicon and manganese present in elemental form in weld metal. The oxide inclusions have been identified by X-ray examination. The total hydrogen content of weld metal is divisible into two parts, one of which escapes from the metal at room temperatures whilst the other is held more or less permanently. The total hydrogen is approximately proportional to the total available hydrogen in the electrode coating, but the partition of the gas between the two forms is not constant for a given electrode and is apparently influenced by factors which are not yet understood. The effect of heat-treatment on the microstructure and on the precipitation of the nitride-bearing constituent has been studied, but no attempt has been made to correlate the constitution of weld metal with its mechanical or other properties. The form of combination of sulphur—as manganese sulphide—has been established by X-ray examination, and some suggestions in connection with the apparently anomalous sulphur prints given by arc-weld metal are put forward.

Gas Evolution in Arc Welding Steels and Its Effect upon the Welding Process. M. C. Smith. (Welding Journal, 1945, vol. 24, Apr., pp. 226-S-229-S). The evolution of gases during the arc-welding process and the decarburisation of the parent metal and the weld metal are discussed. The theory is advanced that the evolution of carbon monoxide causes miniature explosions at the electrode tip and this projects molten metal away from the rod.

Identifying the Constituents of Welding Electrode Coatings. R. C. Vickery. (Iron Age, 1945, vol. 155, Apr. 19, pp. 62-66). See p. 14 A.

The Power-Distribution Problem in Arc Welding. H. W. Pierce and C. E. Smith. (Electrical Engineering, 1945, vol. 64, Apr., pp. 178-184). The general principles of power distribution for arc welding are discussed and their application for providing an adequate, flexible and economical distribution system in a typical shipyard is described.

Danger of Failure in Welded Structures Greatly Reduced by Low-Temperature Stress Relief. T. W. Greene and A. A. Holzbaur. (Steel, 1945, vol. 116, Apr. 23, pp. 110, 142-144). A technique for relieving the residual stresses in welded structures, particularly in shipbuilding work, is described. It consists of simultaneously traversing the heat-affected zones on each side of the weld with two oxy-acetylene torches at a speed such that the steel is not heated above 350-400° F.

Normalizing vs. Stress Relieving. O. Schmidt and E. Jöllenbeck. (Welding Journal, 1945, vol. 24, Mar., pp. 185-S-192-S). This is an abridged English translation of a paper which was published in *Electroschweissung*, 1942, Oct., pp. 141-148; Nov., pp. 156-162. The differences in the microstructure and mechanical properties of welded low-carbon steel boiler plates after normalizing and after stress-relieving were studied. Data from numerous tensile, bend and impact tests are presented and discussed. These indicate that the two forms of treatment should be regarded as technically equal.

Stress Relief of Weldments for Machining Stability. J. R. Stitt. (Ohio State University Studies, Nov., 1944, Engineering Experiment Station

Bulletin No. 121). An account is given of an investigation of the effect of stress-relieving heat-treatments at maximum temperatures of 900°, 1000°, 1100°, 1200°, 1300°, and 1400° F. on the stability during machining of welded structures of three low-alloy chromium-molybdenum steels and one chromium-nickel-molybdenum steel.

Graphitization of Welded and of End-Quenched Carbon and Molybdenum Steels. G. V. Smith and S. H. Brambir. (Welding Journal, 1945, vol. 24, Mar., pp. 153-S-157-S). This is an account of investigations undertaken jointly by the American Society for Testing Materials and the American Society of Mechanical Engineers in which the graphitization of welded 0.15-0.80% carbon steels and of low-carbon 0.5%-molybdenum steels were examined for graphite after 1000, 2000 and 3000 hr. at 975-1050° F. Some of the steels were heat-treated at 1300° F. for 4 hr. immediately after welding, and the evidence pointed to this being an effective method of preventing graphitisation. Specimens of the above steels were also end-quenched before submitting them to the prolonged treatment, and none of the molybdenum steels, whether fine or coarse grained, showed any graphite even after 3000 hr. On the other hand, all the carbon steels had graphitised; numerous small nodules of graphite were observed in the martensitic zone at the quenched end, whilst fewer but larger nodules were visible in the pearlite.

Cast Iron Fusion Welding. J. K. Johannesen. (Welding, 1945, vol. 13, May, pp. 167-172). Numerous examples of the application of welding to the repair of cast-iron vessels, brackets and housings are described and illustrated.

CLEANING AND PICKLING OF METALS

(Continued from pp. 15 A-16 A)

Chemistry of Surface Cleaning. R. Sanders. (Iron Age, 1945, vol. 155, Apr. 12, pp. 62-67). The theory of wetting, emulsifying, saponifying, colloidal activity, solvent action and the measuring of pH values is explained and their application in metal cleaning processes is discussed.

The Pickling of Steels. Part VI. Pumping Acid Solutions. Part VII. Heating Pickling Solutions and Waste Acid Treatment Plant. E. W. Mulcahy. (Sheet Metal Industries, 1945, vol. 21, Apr., pp. 620-625, 630; May, pp. 799-805, 809). Continuation of a series of articles (*see* p. 16 A). Mechanical and non-mechanical systems and equipment for pumping pickling acids, steam jets, steam coils and submerged flame burners for heating pickling baths and waste acid neutralising plants are described.

Electrolytic Polishing of Stainless Steel and Other Metals. O. Zmeskal. (Metal Progress, 1945, vol. 47, Apr., pp. 729-736). Methods for the electrolytic polishing of stainless steel are described and lists of solutions for use at low and high voltages are given. A bibliography with 114 references to the literature on electrolytic polishing is appended.

Electrolytic Methods of Polishing Metals. S. Wernick. (Sheet Metal Industries, 1945, vol. 21, Apr., pp. 626-629; May, pp. 844-853, 865). Continuation of a series of articles (*see* p. 15 A). Continuing Part VI., bright zinc plating, the electrolytic polishing of zinc, bright cadmium plating and plating cadmium with an acid electrolyte are discussed. The electrobrightening of copper and silver is described in Part VII.

Mechanical and Metallurgical Advantages of Shot Peening. O. J. Horger. (Iron Age, 1945, vol. 115, Mar. 29, pp. 40-49, 100; Apr. 5, pp. 66-76, 146-149). Tests are described which demonstrate the advantages

of shot-peening spiral and leaf-springs, gear-teeth, crankshafts and other parts, especially with regard to the improvement in the fatigue strength. The effects of the shot size and the time under blast are discussed and details of the equipment are given.

Shot for Metal Peening. O. E. Harder and J. T. Gow. (Steel, 1945, vol. 116, Apr. 2, pp. 111-112, 172). The properties of four types of cast-iron shot for metal peening are discussed. The types are: (a) Chilled iron; (b) completely malleablised chilled iron; (c) partially malleablised chilled iron; and (d) malleablised quenched and tempered iron.

Surface Treatment for Metals. F. A. Morral. (Wire and Wire Products, 1945, vol. 20, Apr., pp. 272-277). Tables are presented giving details of a variety of methods for the cleaning and coating of metal surfaces together with the trade names of the processes.

Cleaning Metal with New Oxidizing-Reducing Process. G. W. Birdsall. (Steel, 1945, vol. 116, May 7, pp. 104-106; 130-136). The Kolene process of cleaning cast iron for subsequent tinning is described. This has been previously described by T. E. Eagan (*see* Journ. I. and S.I., 1945, No. I., p. 83 A).

COATING OF METALS

(Continued from pp. 17 A-18 A)

Wetting Agents—Their Use in Electroplating and Allied Processes. H. Silman. (Journal of the Electrodepositors' Technical Society, 1944, vol. 19, pp. 131-146). The properties of the following wetting agents are reviewed: (a) "Turkey Red Oil" produced by the action of sulphuric acid on castor oil; (b) sulphated fatty alcohols; (c) aryl alkyl sulphonates; (d) cation-active materials; and (e) petroleum derivatives. Methods of testing them and their application in cleaning and plating processes are discussed.

The Production of Machinable Chromium Deposits. G. E. Gardam. (Journal of the Electrodepositors' Technical Society, 1945, vol. 20, pp. 69-74). Investigations of methods of depositing a machinable chromium coating on steel are described. The presence in the chromium plating solution of considerable quantities of a trivalent metallic ion increases the cathodic current efficiency of chromium deposition at high temperatures, and also permits the production of a soft machinable deposit over a wide range of current density. Examples of suitable trivalent ions are iron (15-30 g./l.) and chromium (15-30 g./l.). Aluminium is also efficacious, and is best added as the hydroxide.

Production Galvanizing of Ammunition Cases. A. T. Baldwin. (Iron Age, 1945, vol. 155, Mar. 8, pp. 68-70). A description is given of the plant and processes developed for the hot-dip galvanising of sheet-metal ammunition boxes measuring 11 × 11 × 20 in. deep.

Galvanizing. W. H. Spowers, jun. (Journal of the American Society of Naval Engineers, 1945, vol. 57, Feb., pp. 78-90). A description is given of the pickling and galvanizing plant and practice at the American Navy Yard, Portsmouth, New Hampshire.

Palm Oil Recovery System. H. P. Wilkinson. (Steel, 1945, vol. 116, Apr. 23, pp. 90-91, 112-115). A description is given of the palm-oil recovery and circulation system at the tinplate mill of the Weirton Steel Co. The oil from seventeen tinning pots is cleaned by two centrifuges which remove 30-40 lb. of impurities in an 8-hr. shift. The quality of the tinplate has been improved and the consumption of palm oil has been reduced by 25% since this system was installed.

Devices for Controlling the Distribution of Electrodeposits. C. J. Leadbeater. (Journal of the Electrodepositors' Technical Society, 1943,

vol. 19, pp. 35-48). Devices for controlling the distribution of electro-deposits, with special reference to building up worn parts with nickel or chromium, are described in detail under the following headings: (1) Devices integral with the component or suspender; (2) those used in the plating bath; and (3) the general organisation of the plating department.

The Reclaiming and Hardening of Engineering Components by Electro-Deposition. H. Merryweather. (Manchester Association of Engineers, 1945, Feb., Advance Copy: Engineering, 1945, vol. 159, May 18, pp. 398-400; May 25, pp. 419-420). The development of electro-plating as a means of depositing nickel, cadmium or chromium to build up worn surfaces on parts of aero-engines, and the plating technique are described in detail.

Problems Connected with Reclamation of Worn Parts by the Metal-Spraying Process. W. E. Ballard. (Proceedings of the Institution of Mechanical Engineers, 1945, vol. 152, No. 1, pp. 4-7). To assist those faced with the problem of repairing a worn part information is presented in the form of answers to the following questions: (a) Is metal-spraying a suitable method? (b) If so, how must the work be prepared for spraying? (c) What method of spraying and which metal should be used? (d) What finish is necessary?

Cold Metal Spraying and Its Application to Internal Combustion Engines. V. G. Young. (Diesel Engine Users' Association: Mechanical World, 1945, vol. 117, May 11, pp. 517-519). Many examples of the repair of worn parts by metal-spraying are described.

The Repair of Worn or Over-Machined Parts by Electrodeposition. A. W. Hotherhall. (Proceedings of the Institution of Mechanical Engineers, 1945, vol. 152, No. 1, pp. 8-12). See Journ. I. and S.I., 1944, No. 1, p. 97 A.

Porcelain Enamel on Steel Components in the Postwar Era. G. H. McIntyre. (Pressed Metal Institute: Steel Processing, 1945, vol. 31, Feb., pp. 100-102). Probable post-war developments in the porcelain enamelling industry are discussed.

Black Finishes for Steel. H. Silman. (Journal of the Electrodepositors' Technical Society, 1945, vol. 20, pp. 77-92; Metal Industry, 1945, vol. 66, May 25, pp. 330-332; June 8, pp. 362-363). Processes of obtaining three main types of black finish on steel are reviewed. These are: (1) Oxide coatings formed on the iron surface by oxidising; (2) phosphate coatings suitably stained and impregnated; and (3) black deposits (e.g., black nickel) or coatings of other metals, such as copper, coloured black by chemical means.

Application and Selection of Organic Finishes. C. R. E. Merkle. (Pressed Metal Institute: Steel, 1945, vol. 116, May 7, pp. 108-109, 176-190). The preparation of metal surfaces for coating and the application and baking of synthetic-resin coats are described and discussed.

Resin Coatings Baked by Induction Heating. A. P. Mazzucchelli and R. E. Nicolson. (Iron Age, 1945, vol. 155, May 3, pp. 46-50). An illustrated description is given of equipment for the continuous baking of synthetic-resin coatings on $1\frac{1}{2}$ -in.-dia. steel tubes. The tubes are withdrawn vertically from the bath of the coating solution and pass through an induction-heating coil at a speed of about 3 in. per min.

PROPERTIES AND TESTS

(Continued from pp. 42 A-45 A)

The Shape of a Material's Reaction to Force.—Part II. A. C. Vivian. (Metallurgia, 1945, vol. 31, Apr., pp. 301-307). The manner of presenting

the properties of materials which was discussed in Part I. (*see* p. 42 A) is expanded in Part II. Stress-strain and viscosity curves for a simple hypothetical material are considered. The conventional stress-strain curve for iron and steel held the promise of a truly elastic range in metallic materials in general and gave rise to conceptions of the constant elastic modulus, the limit of proportionality, the proof resilience and the point of mechanical failure, but if stress-strain curves were drawn showing the strain on a much larger scale than that usually employed, these expectations would not be realised. There is good reason to believe that the stress-strain curve must be logarithmic in shape. Reasons for the inherent logarithmic shape of the typical stress-strain curve are given.

Detection and Prevention of Incipient Cracking in Firebox and Boiler Steel. R. McBrien. (Metal Progress, 1945, vol. 47, Mar., pp. 524-527). The causes and detection of cracks in fireboxes between stay-bolts is described. A 0.50%-molybdenum steel is recommended for fireboxes and the properties of the steel at the operating temperature rather than at room temperature should be studied.

A Photo-Induction Defectoscope. M. M. Sliozberg. (Zavodskaya Laboratoriya: Metallurgia, 1945, vol. 31, Apr., pp. 293-295). A method of detecting defects in metals by means of photo-electric measurements is described.

Practical Strain Analysis by Use of Brittle Coatings. G. Ellis. (Proceedings of the Society for Experimental Stress Analysis, 1943, vol. 1, No. 1, pp. 46-53). The use of brittle coatings to study the distribution of stresses in metals is discussed and some practical examples are given.

Measurement of Dynamic Stress and Strain in Tensile Test Specimens. R. O. Fehr and E. R. Parker. (Proceedings of the Society for Experimental Stress Analysis, 1943, vol. 1, No. 1, pp. 76-82). A Riehle impact testing machine for the measurement of stress and strain when the force is applied at a high rate of speed is described and the results of some tests on a low-carbon steel and on duralumin are presented and discussed. All the values obtained in the dynamic tensile tests were higher than the corresponding values obtained in the static tensile tests.

The Use of the Resistance Wire Strain Gage in Stress Determination. C. H. Gibbons. (Proceedings of the Society for Experimental Stress Analysis, 1943, vol. 1, No. 1, pp. 41-45). Brief descriptions are given of the commercially available resistance-wire strain gauges and their fields of application are discussed.

Electrical Instruments for Strain Analysis. C. M. Hathaway. (Proceedings of the Society for Experimental Stress Analysis, 1943, vol. 1, No. 1, pp. 83-93). The history of the development of the electric strain gauge is presented and descriptions of modern strain gauges, oscillographs and associated equipment are given with notes on their applications and limitations.

The Use of Electric Strain Gages to Measure Repeated Stresses. H. J. Grover. (Proceedings of the Society for Experimental Stress Analysis, 1943, vol. 1, No. 1, pp. 110-115). A description is given of electrical resistance strain-gauge equipment for measuring periodic strains superimposed on constant strains.

Yielding and Fracture of Medium-Carbon Steel under Combined Stress. E. A. Davis. (Journal of Applied Mechanics, 1945, vol. 12, Mar., pp. A-13-A-24). The results of combined stress tests on a 0.23%-carbon steel are presented and discussed, particular attention being paid to the magnitude and distribution of the stresses and strains at the instant preceding fracture. Before the ultimate strength was reached the material behaved as though it were perfectly isotropic; beyond the point of maximum load it did not behave as an isotropic body, and the distribution of the

three principal strains was not the same as it was before necking started. This was true even in pure axial tension when the specimens were neither round nor square in cross section. At fracture the material appeared to be weak in the circumferential direction.

How Rail Failures Are Being Prevented. R. E. Cramer. (Metal Progress, 1945, vol. 47, Mar., pp. 521-524). Different types of fracture in rails are described and illustrated and particulars are given of I. C. Mackie's method for the controlled cooling of rails in boxes; this method has very greatly reduced the occurrence of cracks.

Improving the Railroad Axle. O. J. Horger. (Metal Progress, 1945, vol. 47, Mar., pp. 529-532). Fatigue cracks in railway-wagon and passenger-coach axles are discussed, and two methods of preventing their occurrence are described. The first is the use of a heat-treated tubular axle of 0.35%-carbon steel in which a favourable fatigue-strength/weight ratio is obtained by quenching the outer surface only. This treatment produces high compressive stresses in the surface. The second is to obtain a better flow of stress along the axle by machining a circumferential groove up to $\frac{7}{16}$ in. deep adjacent to the inside face of the wheel hub; the surface of this groove is rolled under pressure.

The Biaxial Fatigue Strength of Low-Carbon Steels. G. K. Morikawa and LeVan Griffis. (Welding Journal, 1945, vol. 24, Mar., pp. 167-S-174-S). Thin-walled tubular specimens of welded and unwelded 0.20%-carbon steel were fatigue-tested under various combinations of circumferential and axial stresses. The stresses were synchronised in phase and were both tensile. Changes in the ratio of the principal stresses had only a slight effect on the endurance limit. The endurance limit was about 15% less when the stresses in the transverse direction predominated. The fatigue strength of the unwelded specimens was about 15% greater than that of the welded specimens. The anisotropy of this rolled steel remains a major factor in the occurrence of failure, even after annealing.

Residual Stresses and Fatigue Studies. O. J. Horger, H. R. Neifert and R. R. Regen. (Proceedings of the Society for Experimental Stress Analysis, 1943, vol. 1, No. 1, pp. 10-18). A report on two investigations is presented. In the first, the residual stresses were determined in three heat-treated steel shafts 2 in. in dia., all of which were quenched in water from 1525° F., but were then tempered at three different temperatures. In the second, fatigue tests were carried out on 2-in.-dia. specimens of heat-treated S.A.E.-4340 steel each with a very small transverse hole, with and without the addition of residual stresses produced by cold-rolling. The surface-rolling of the specimens before drilling increased the fatigue strength by 28%.

Indentation Hardness. G. C. Richer. (Metallurgia, 1945, vol. 31, Apr., pp. 296-299). The relationship between indentation hardness values and the true stress-strain-curve are discussed. The suggestion is made that the "arrest point" of an indentation test marks the localised completion of that stage of the process of mechanical deformation during which the stored energy ratio remains substantially constant.

Hardenability Behaviour of Carburizing Grades of NE and Automotive Alloy Steels. A. S. Jameson. (Steel, 1945, vol. 116, May 7, pp. 110-120, 192). The results of several series of end-quench hardenability tests on uncarburised and carburised N.E. and S.A.E. steels are presented and discussed. In particular the hardness variations along specimens in the as-quenched state and after grinding off the surface layer to different depths are compared.

Hardenability and the Steel Casting. K. L. Clark and J. H. Richards. (Transactions of the American Foundrymen's Association, 1945, vol. 52, June, pp. 1325-1346). The object of the investigation described was to

determine whether the hardenability of forged steel is the same as that of cast steel of the same composition. The tests were made with 14 low-alloy chromium-nickel-molybdenum steels, some containing copper and aluminium and two containing boron. For practical purposes, cast steels can be said to have the same hardenability as forged steels of the same composition and grain size. Within the range of steels studied, normalising treatments at as high as 1090° C. prior to quenching from 900° C. did not materially affect the hardenability of cast steel except in so far as they altered the as-quenched grain size. The methods and factors used for calculating the hardenability of wrought steels applied also to cast steels. It appeared that boron can greatly increase the hardenability of cast steel, but some of its effect is lost if high pouring temperatures are necessary. When relatively high hardenability is desired in 0.35–0.45%-carbon cast steels, the addition of strong carbide formers such as chromium and molybdenum should be limited, whilst more should be added in the case of 0.15–0.25%-carbon steels.

Relationship of Brinell Hardness and Yield Stress in Certain Cast Steels.

T. W. Ruffle. (Proceedings of the Institute of British Foundrymen, 1943–44, vol. 37, pp. A-117–A-121). An investigation of the relationship between the Brinell hardness and the tensile properties of 0.25%-carbon 1.5%-manganese electric-furnace cast steel is reported. The following equations were found to be valid for this steel when heat-treated and tested in the manner specified :

$$\text{Yield Point} = (\text{Brinell No.} \times 0.08) + 12.56.$$

$$\text{Ultimate Strength} = (\text{Brinell No.} \times 0.15) + 13.32.$$

The hardness test could therefore be used as a non-destructive acceptance test for the castings in question.

Galling and Seizing. (Meehanite Research Institute of America: Metallurgia, 1945, vol. 31, Apr., pp. 315–316). A brief description is given of a two-gauge dynamometer and friction-testing equipment for mounting on the table of a vertical milling machine in such a way that the vertical load with which a rotating test member is pressed on to a stationary test member and the torque can be measured. The results of tests with steel on bronze, steel on graphitic cast iron, steel on Meehanite, and Meehanite on Meehanite are presented and discussed.

A Magnetic Comparator for Sorting of Ferrous Alloys. A. A. Townsend. (Australasian Engineer, 1945, vol. 44, Mar. 7, pp. 42–43). A brief account is given of the development and final form of a magnetic testing device for sorting steel bars. The apparatus consists of two test coils with an amplifying instrument and a milliammeter. One coil is placed over the end of a standard bar, and the second coil is placed over the bar to be tested; any difference in the magnetic permeability is indicated by the instrument.

Magnetic Examination of Metals. N. S. Akulov. (Iron and Steel Institute, 1945, Translation Series, No. 222). This is an English translation of a paper which appeared in Vestnik Metallopromyshlennosti, 1940, No. 4–5, pp. 123–129. The need for increased facilities in the U.S.S.R. for the non-destructive testing of metals is stressed and brief descriptions are given of some magnetic methods of testing which have been developed in the Magnetism Laboratory of the Moscow University and Central Engineering Institute.

Permanent Magnets. R. L. Sanford. (United States National Bureau of Standards, Aug., 1944, Circular No. C448). This circular gives general information regarding the composition, treatment and properties of permanent-magnet materials, and on the design and testing of permanent magnets.

Nitrogen in Chrome-Nickel Steels. R. Scherer, G. Riedrich and H. H. Kessner. (Iron Age, 1945, vol. 115, Mar. 29, pp. 56–60). This is an

English translation of a paper which appeared in *Stahl und Eisen*, 1942, vol. 62, Apr. 23, pp. 347-352 (*see* Journ. I. and S.I., 1942, No. II., p. 121 A).

The Effect of Copper on the Properties of Cast Carbon-Molybdenum Steel. N. A. Zeigler and W. L. Meinhart. (Transactions of the American Foundrymen's Association, 1945, vol. 52, June, pp. 1151-1171). An investigation of the effect of copper on steels containing 0.1-0.2% of carbon and 0.5-1.0% of molybdenum is reported. Increasing the addition of copper up to 1.5% may increase the tensile strength by almost 100%; at the same time the increase in hardness and the decrease in ductility are not great enough to be objectionable. The addition of 1% of copper to a 0.1%-carbon 0.5%-molybdenum steel develops properties in the heat-treated steel equivalent to those of a cast molybdenum steel containing about 0.25% of carbon. The addition of copper reduces the maximum hardness of the heat-affected zone of welded carbon-molybdenum steel.

Mechanical Properties and Weldability of High Strength Plate. G. F. Comstock. (Metal Progress, 1945, vol. 47, Mar., pp. 511-520). An earlier investigation of the properties of specimens of laboratory heats of manganese-titanium steels (*see* Journ. I. and S.I., 1945, No. I., p. 157 A) has been extended to cover plates produced by several American mills. Thirteen analyses of steel were tested; these contained up to 1.59% of manganese and some were alloyed with nickel, chromium and molybdenum. The excellence of manganese-titanium steel for high-strength weldable plates was confirmed. For plate to be used in the as-rolled state the preferred titanium content is 0.02-0.04% with carbon at 0.13-0.15% and manganese at 1.15-1.30%.

Boron in Steel and Cast Iron. G. von Hofsten. (Jernkontorets Annaler, 1945, vol. 129, No. 3, pp. 166-170). (In Swedish). A review of the literature on the effect of boron in steel and cast iron is presented.

Selection of Bar Steel Used As-Rolled or Drawn. J. H. Frye. (Metal Progress, 1945, vol. 47, Mar., pp. 497-504). The characteristic properties of cold-finished steel bars, which include hot-rolled bars finished by cold-drawing, turning and polishing, turning and grinding, or cold-drawing and grinding, are discussed. Cold-drawn low-carbon steel bars are subject to ageing, especially during the first seven days after drawing. The ageing effect is greater for bars slightly reduced than for those which have been heavily reduced in section.

Previewing the Future for Low-Alloy High-Strength Steels. F. D. Foote. (Steel, 1945, vol. 116, Apr. 23, pp. 102-104). The properties and applications, particularly for railway wagons and passenger coaches, of low-alloy structural steels are discussed.

Engineering Properties of Heat Treated Cast Irons. J. S. Vanick. (American Foundrymen's Association: American Foundryman, 1945, vol. 7, Apr., pp. 11-15). The benefits to be derived from heat-treating different qualities of cast iron are discussed.

Testing Castings—Steel. W. Crafts. (American Foundrymen's Association: Canadian Metals and Metallurgical Industries, 1945, vol. 8, Mar., pp. 31-33). Methods of testing steel castings are reviewed. The application of statistical methods to determine what proportion of a product requires testing to guarantee a certain result is advocated.

Design of Test Coupons for Cast Steel. R. C. Wayne, H. F. Bishop and H. F. Taylor. (Transactions of the American Foundrymen's Association, 1945, vol. 52, June, pp. 1251-1265). The development of an efficient design of test coupon for cast steel is described, the object being to provide one for which the pattern and moulding would be simple, and in which there would be no shrinkage defects. It had also to be easily cleaned and the machining of the individual specimens should be easily performed. The most suitable design was found to be one resembling a 6 or 8-toothed gear wheel with

rounded teeth, each projection being cut off to make a single specimen. This design was economical in steel as only a small riser was required.

Sampling Schemes for Qualitative Inspection. A. W. Swan. (Proceedings of the Institution of Mechanical Engineers, 1945, vol. 152, No. 1, pp. 81-92). If 100% inspection is not necessary or possible, inspection by sampling is used instead. It may be either quantitative, involving the direct measurement of the size, weight or density of each unit in a sample, or qualitative, in which case the result is counted as a success or a failure (*e.g.*, up to 2 blemishes per sq. in. is a success and more than 2 a failure). Factors affecting the method of qualitative inspection to adopt are discussed.

Inspection Efficiency. J. C. Edwards and W. A. Bennett. (Proceedings of the Institution of Mechanical Engineers, 1945, vol. 152, No. 1, pp. 69-75). The numerous directions in which improvement can be sought in engineering inspection are outlined. It is shown how direct improvements in efficiency can be effected by carefully planned methods of recording results, including the use of statistical quality control.

A Proposed Matched Set of Steels. J. E. Erb. (Metal Progress, 1945, vol. 47, Apr., pp. 724-728). The author protests against the excessive number of specifications for steel and proposes a simple system of classification into five groups.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 45 A-46 A)

A Simple Method for Mounting Lead Foils to Produce Better X-Ray Intensifying Screens. J. Delisa. (Steel, 1945, vol. 116, Apr. 30, pp. 110-115). With the increased power of X-ray apparatus fluorescent screens have been replaced by intensifying screens of lead foil 0.005 and 0.010 in. thick. To prevent these from being pitted, wrinkled or creased a simple method of mounting the thin lead foil on a sheet of unwanted film from the record files has been devised. The method of mounting is described.

Some Crystallographic Effects in Metals. D. W. Davison. (Sheffield Metallurgical Association: Iron and Coal Trades Review, 1945, vol. 150, May 18, pp. 815-816). The fundamentals of precipitation in the cooling of steel with particular reference to the Widmanstätten structure are discussed. In the process of nucleation and growth when pearlite, martensite and intermediate structures form it is a question of which happens first, the $\gamma \rightarrow \alpha$ change or the precipitations of cementite. The octahedral precipitation characteristic of the $\gamma \rightarrow \alpha$ change exists in the low-temperature transformation products bainite and martensite. This suggests that the $\gamma \rightarrow \alpha$ change has happened first and, as it were, has grasped the opportunity of determining the crystal architecture. The cementite crystals then form, if time and temperature conditions permit, within this predetermined layout.

Trouble Shooting—Malleable. M. E. McKinney. (American Foundrymen's Association: Canadian Metals and Metallurgical Industries, 1945, vol. 8, Mar., pp. 33-35). The testing of malleable iron castings is considered with particular reference to the interpretation of micrographs.

The Iron/Iron-Sulphide/Iron-Boride System. R. Vogel and T. Heumann. (Iron and Steel Institute, 1945, Translation Series, No. 227). An English translation is presented of a paper which appeared in Archiv für das Eisenhüttenwesen, 1944, vol. 17, May-June, pp. 271-274 (*see* Journ. I. and S.I., 1945, No. I., p. 140 A).

CORROSION OF IRON AND STEEL

(Continued from pp. 23 A-24 A)

An Investigation into Corrosion Caused by Aromatic Benzole Absorption Oil. O. B. Wilson. (Coke and Smokeless Fuel Age, 1945, vol. 7, Feb., pp. 34-38; Mar., pp. 53-56; Apr., pp. 73-77; May, pp. 93-99). A detailed account is given of an investigation of the corrosion of heat exchangers, preheaters and stripping stills in benzole recovery plants, in particular that of the U-tubes in the preheaters. Ammonium thiocyanate has the greatest corrosive effect on the parts of the stripping plant. The action of ammonia on carbon bisulphide produces ammonium thiocyanate, every eight molecules of ammonia producing three molecules of ammonium thiocyanate under ideal conditions. The time of contact is an important factor. The amount of ammonia passing to the benzole scrubbers should be reduced to the minimum. The oil used in the benzole scrubbers should contain no water if possible. Tar acids are corrosive to cast iron, and these should be removed from the new oil by soda washing. Hydrocyanic acid also plays a considerable part in this corrosion problem; a means of reducing the acid content of the gas entering the scrubbing system is indicated. It is an expensive process to reduce the ammonia content of the crude gas entering the oil scrubbers, consequently a nickel-chromium cast iron, which has proved successful in resisting this corrosion, is recommended. The evidence suggests that ammonia and its salts play an important part in the mechanism of the corrosion process, but their action on cast iron is greatly accelerated by galvanic action.

Pipe Service Tests on Baltimore Water. C. F. Bonilla. (Electrochemical Society, Apr., 1945, Preprint No. 20). Corrosion tests, some of which lasted fifteen years, with cold and hot lime-treated Baltimore water on several types of wrought iron and steel pipe are reported.

Recommendations for Using Steel Piping in Salt Water Systems. P. Ffield. (Journal of the American Society of Naval Engineers, 1945, vol. 57, Feb., pp. 1-20). The corrosion of steel pipe lines by salt water and the factors affecting the rate of corrosion are discussed. Recommendations on the design of pipe lines in ships with a view to retarding or preventing corrosion are made.

The Use of a Tin Undercoat to Improve the Corrosion Resistance of Painted Steel. E. S. Hedges and L. A. Jordan. (Iron and Steel Institute, 1945, this Journal, Section I). The effectiveness of tin undercoats on painted steel in retarding corrosion has been examined. The investigations covered electrodeposits of tin from both the alkaline and acid tin baths, using thicknesses of 0.000008 and 0.00003 in., and the effect of flash-melting the tin coatings and of oxidizing the tin surface by chemical treatments; in addition, specimens of plain steel, hot-dipped tinplate and phosphated steel were included in the series. Twelve different paints were applied, including linseed-oil paints, nitrocellulose lacquer, stoving paints, and air-drying japans. Accelerated corrosion tests show that treatment with electrodeposited tin, especially when followed by the application of the T.R.I. (Tin Research Institute) anti-rusting oxide film, adds very greatly to the protection afforded by the paints. The best treatment was 0.00003 in. of tin electrodeposited from the sodium stannate bath and further protected by the T.R.I. film.

Anomalous Inactivation of Heavy Metal Antifouling Paints. G. H. Young and G. W. Seagren. (Nature, 1945, vol. 155, June 16, pp. 715-717). It has been established that cuprous-oxide and metallic-copper antifouling paints when applied over bare steel rapidly lose their anti-

fouling efficiency after about one month's immersion. Tests on panels submerged at Daytona Beach, Florida, indicated that corrosion products on one part of a panel can be washed across the rest of the panel by currents and passivate the antifouling paint over which they pass, thus causing bands of fouling to appear. Tests were also made to determine the effect of the accidental contact of steel bolts or anchor chain against an antifouling paint on a wood hull. Only in the case of non-insulated contact direct to the face of the metallic copper formula was there an appreciable passivation for finite distances from the base steel; this distance was of the order of 2 in. only.

Failure of Spring Loops by Stress Corrosion. G. Brewer and H. C. Ihlen. (Metal Progress, 1945, vol. 47, Apr., pp. 707-712). An investigation of the cause of failure of spring clips $5\frac{1}{2}$ in. long made of 0.068-in. dia. steel wire is described. Cracks were found to have developed on the inside of the loops at each end of the wire.

The Comparative Effect of Carbon and Nitrogen on Intergranular Corrosion of 18/8 Stainless Steel. H. H. Uhlig. (Electrochemical Society, Apr., 1945, Preprint No. 13). The effect of high nitrogen content on the susceptibility of stainless steel to corrosion was studied. This 18/8 steel, containing 0.2% of nitrogen and 0.007% of carbon, was susceptible to intergranular corrosion in a pickling solution consisting of HNO_3 (15% by volume) and HF (3% by volume). A very pure 18/24 chromium-nickel steel containing only 0.003% of carbon and 0.006% of nitrogen was also found to be subject to intergranular corrosion. The theory that this form of corrosion is caused by the precipitation of nitrides therefore requires revision.

On the Kinetics of the Formation of Oxide Films on the Surface of Metals. J. Frenkel. (Journal of Physics, 1944, vol. 8, No. 4, pp. 225-229). Equations are developed for calculating the kinetics of the primary process of the adsorption of oxygen by a metal surface and its rate of diffusion into the interstices of the crystal lattice.

Rust Preventatives. (Steel, 1945, vol. 116, Apr. 2, pp. 106-108, 149-156). The properties of solvent and oil-type coatings, mainly for the short-time protection of metal surfaces, and some humidity and salt-spray tests devised by E. F. Houghton and Company are discussed.

An Apparatus for Measuring Corrosion. M. Cohen. (Electrochemical Society, Apr., 1945, Preprint No. 19). An apparatus for accelerated corrosion tests for metals in solutions is described and some results obtained with it are presented and discussed. The specimen rests in a horizontal glass tube each end of which is connected by rubber tubing to a vertical glass reservoir of 250 c.c. capacity. One reservoir is kept stationary whilst the second is raised and lowered by mechanical means at a controlled rate, thus causing the water (or other corroding solution) to wash to and fro over the specimen. A convenient number of such assemblies may be mounted on a single stand so that several tests can be carried out simultaneously.

Equipping a Corrosion Laboratory. F. K. McKean. (Transactions of the Canadian Institute of Mining and Metallurgy, 1945, vol. 48, pp. 86-93). A description is given of the equipment and layout of the laboratory for general corrosion testing which forms part of the new Physical Metallurgy Research Laboratories of the Department of Mines and Resources at Ottawa.

BOOK NOTICES

(Continued from pp. 24 A-25 A)

HAYWOOD, F. W., and A. R. WOOD. "*Metallurgical Analysis by Means of the Spekker Photo-Electric Absorptiometer.*" 8vo, pp. xii + 128. Illustrated. London, 1944: Adam Hilger, Ltd. (Price 18s.)

This book is intended as a manual of instruction for use in conjunction with the model of the Spekker Absorptiometer now obtainable. By far the larger portion of the book is devoted to detailed, step-by-step instructions for some twenty-six commonly required metallurgical analyses using the instrument.

For the routine control of metallurgical products the absorption method of analysis possesses the great advantages of speed and simplicity, and a number of composite schemes are set out in the form of tables showing each step in the complete analysis of the major alloying elements in irons, steels, copper alloys and light alloys. The analyses are carried out from only one or two original weighed samples, the sample being dissolved and the diluted solution split into a number of aliquot portions, each portion being separately treated to give a certain colour and then observed in the absorptiometer.

The principles of the photo-electric absorptiometer are set out briefly in the opening pages. Whilst various colorimetric methods of analysis have been in existence for over a century, the absorption technique is only of recent development and is largely due to Vaughan and his collaborators in the Admiralty Inspection Laboratory at Sheffield, to whom the authors acknowledge their indebtedness. The authors are careful to point out that the instrument should not be referred to as a "photo-electric-colorimeter," as the photo-electric cell is used to measure the intensity of the light transmitted, *not* the intensity of colour, the spectrum of the incident light being controlled by means of colour filters. The laws of optical absorption (Beer's Law and Lambert's Law) are stated briefly.

The rest of the book is devoted to practical details of the design and operation of the Spekker Absorptiometer and the methods of calibration, that is the correlation of the "drum reading" and the percentage of given element present. Once calibration graphs have been drawn up for each element they need only be checked once every six months or so.

The limitations of the absorption method of analysis are considered shortly. Whilst the method can be very rapid and simple, especially for routine work, it suffers from the limitation common to all photometric and colorimetric analyses, namely that the final reading taken is related to a limiting concentration of the element concerned. However, various ways of getting over this are put forward.

D. J. O. BRANDT.

INSTITUTE OF PHYSICS. "*Handbook of Industrial Radiology.*" By Members of the Industrial Radiology Group of the Institute of Physics. Edited by J. A. Crowther. 8vo, pp. viii + 203. London: Edward Arnold & Co. (Price 21s.)

This book had its origin in a series of lectures given before the Industrial Radiology Group of the Institute of Physics. As the editor points out in his preface, the application of radiography as one of the few non-destructive tests for internal flaws has played an ever-increasing rôle in war industry, as a result of which many scientists found themselves pitchforked into the job of making radiographic tests for the first time in their experience. Consequently one of the first acts of the newly formed committee of the Industrial Radiology Group was to arrange a series of lectures on the subject, in which the older workers could pass on some of their experience to the new. The attendance at these lectures and the discussions which followed showed how much this was appreciated, and it was decided to make them available to a still larger audience in book form.

As a result the book cannot be expected to be anything in the way of a continuous treatise on the subject, but is essentially written by a number of practical men who are actually working on the subject; it is designed to reach other practical men and aid them in their efforts to improve their technique.

The first chapter is devoted to a short consideration of the physical principles of radiology, and explains the nature of X-rays, the relation of wave-length and

voltage, the wave-length characteristics of target elements, the mechanism of absorption, &c. The quantum theory and the conception of the photon and the modern view of the atom are considered briefly; from this the use of "filtration" is made clear. This chapter is of necessity rather condensed and not very easy to follow unless the reader has already some knowledge of X-ray work, but it serves to show to the newcomer the complex nature of X-rays and the accompanying forms of radiation.

The chapters which follow are all more essentially concerned with the practical side of radiology. The design of X-ray equipment and the circuits involved are set out in Chapter 2, and Chapters 3 and 4 deal with the measurement of various factors such as the voltage, the intensity of radiation, the behaviour of photographic emulsions to X-rays and the use of intensifying screens. Bibliographies and text references are appended.

Of particular interest to metallurgists are Chapters 5 and 6 dealing with the examination of heavy and light metals respectively. The chapter devoted to heavy metals contains much valuable information on the technique of radiographic examination of castings at Messrs. Hadfields and the methods of "blocking-in" castings to even up the thickness and prevent scatter round the edges of the specimen. Much work has been done on the methods of detecting the position of cavities and practical methods of reporting radiographs. The author has endeavoured to develop standard methods whereby the defects discovered by the radiographer may be readily understood and assessed by the metallurgist in a language common to both.

Radiographic inspection of light metals is easier than that for heavy metals and the chapter devoted to this is written in more general terms. Some useful "do's and don't's" in the matter of exposure and set-up are given. The author urges the newcomer not to rely too much on the exposure curves given for various metals by other workers, but to establish his own set of curves for his own apparatus in his own laboratory.

Chapter 7 is devoted to the subject of Gamma Radiography, that is, the use of radium or radon as a source of penetrative gamma rays, instead of the X-ray tube. Gamma radiography finds its most useful application in the examination of iron and steel castings and welds. However, it is not so sensitive as X-ray examination, and the absence of the bulky tubes and related equipment is liable to make the operator underrate the danger of exposing himself to the rays. Some useful information is given regarding the types of defects which may be detected by gamma rays and their appearance on the radiograph, but the author stresses the fact that the rays are not very sensitive and cannot, for instance, be used to detect hair-line cracks in forgings. In his opinion gamma radiography should only be undertaken after a thorough training in the handling of large sources of gamma rays and in the interpretation of gamma radiographs.

The uses of X-ray examination are very wide, and Chapter 8 considers some of these, both from the industrial and criminological point of view. Fluoroscopy, that is examining the radiograph on a fluorescent screen instead of a photograph, has been applied to a large number of inspecting methods. An extensive bibliography arranged under alphabetical headings is appended, from which information can be gained on the use of radiography in all its applications.

The last chapter deals with the very important subject of protection from the dangerous physiological effects of X-rays and gives tables showing the penetrative power of X-rays through lead screens, &c., and a number of rules for X-ray workers.

Finally it should be mentioned that the contributors have all refused any sort of fee for the work put into their respective chapters, and therefore any royalties accruing from the sale of the book will pass to the Benevolent Fund of the Institute of Physics.

D. J. O. BRANDT.

PEARSON, C. E. "*The Extrusion of Metals.*" With a Foreword by R. Genders. 8vo, pp. viii + 205. Illustrated. London, 1944: Chapman and Hall, Ltd. (Price 18s.)

This book is intended as a handy volume of reference for use by all those interested in the subject of extrusion, whether as students or industrialists. It does not set out to be anything in the way of a complete treatise. A list of references is compiled at the end of each chapter whereby the subject may be studied more closely.

The author first outlines the historical development of the extrusion process as applied to lead and other soft metals, dating from 1797, when Joseph Bramah was granted a patent for making "pipes of lead or other soft metal of any given length without joints." The early French and German patents for lead cable

sheathing presses are noted, and special reference made to the work of George Alexander Dick, the founder of the Delta Metal Co., who pioneered the extrusion of harder materials, brass and bronze, and overcame many of the difficulties associated with the higher temperatures necessary for the working of these alloys.

The subject of extrusion of lead cable sheathing receives extensive treatment in a whole chapter, and some of the modern continuous cable sheathing presses are described and illustrated in some detail. Mention is also made of the various defects which may occur in cable sheathing.

The design and development of modern billet-piercing presses for the extrusion of steel and similar hard metals are considered in detail, the text being plentifully illustrated with photographs and line drawings, and the difficulties encountered with horizontal presses due to the thermal expansion of the working parts are clearly explained. Reference is made to the design and metallurgical properties of dies and mandrels and the mechanism of tapered extrusion. The author deals only briefly with the design of hydraulic machinery for extrusion, as this is more of an engineering problem. A brief review of modern billet-heating practice is given.

The chapter on the flow of metals during extrusion contains much of the author's own investigational work and is illustrated by a number of excellent photographs. The flow has been analysed by slitting a billet longitudinally before extrusion and cutting a "net pattern" on the inside face of one of the halves. The halves are then replaced and extruded together, and re-separated after extrusion. The nature of the flow can then be judged from the distortion of the pattern.

The mathematical treatment of the mechanism of extrusion is considered, various formulae are quoted, and reference is made to the work of a number of Continental investigators. The influence of temperature and die shape on the speed of extrusion and the finish on the work are also dealt with and a number of references given.

Considerable data have been set out in the form of tables covering practical details of extrusion methods for various copper-base alloys, cupro-nickel and light alloys, and the mechanical properties attainable in extruded sections. These, and the references quoted, should be of considerable value to manufacturers and others who may be proposing to introduce extrusion methods or to use extruded sections.

Finally, the author deals with some of the aspects of impact-extrusion for the manufacture of collapsible tubes, and other special applications, such as the Hooker impact process and some of the American patents for the production of small parts by a mixture of extrusion and forging.

It is unfortunate in one way that the book is only 8½ in. × 4½ in. in size, as this has meant that some of the line drawings, particularly those of complete machines, have had to be so compressed that it is difficult to follow the detail. Most of the drawings, however, are excellent. D. J. O. BRANDT.

SANDERS, T. H. "*Springs: A Miscellany.*" (In two vols.) Volume II. Including Chapters XIV. to XXII. and Appendix. 8vo. pp. xv + 599. Illustrated. London: The Locomotive Publishing Co., Ltd. (Price 25s.)

This book (the first volume of which was reviewed in these columns in 1941) covers a very wide field, including the history, manufacture, testing, applications and underlying theory of springs. In this volume, Chapter XXI. gives interesting historical details of early railway and road vehicle spring suspensions. A long chapter (XIX.) deals in detail with modern railway suspensions, defects in which are also dealt with in Chapter XVI. on the derailment of vehicles (which also discusses the magnetic detection of cracks). Miscellaneous applications are discussed in Chapter XXII., whilst Chapter XX. (recent spring improvements) deals mainly with road vehicle suspensions since 1930.

Machinery for manufacturing laminated springs is the main topic of Chapter XVII. on recent machinery and details, whilst an interesting Chapter (XIV., on combination machines and fatigue testing) describes many different forms of combined scragging and load-testing machines and fatigue-testing machines; the author remarks on the comparative neglect of fatigue work on springs in this country, which has to a considerable extent been remedied since the book was written.

The more theoretical aspects receive a less satisfactory treatment; Chapter XV. on dynamic deflections deals in an elementary way with the effect of irregularities in the road or track, but no clear distinction is drawn between fluctuating loads and true dynamic deflections. Steel, fatigue and fracture are

discussed in Chapter XVIII.; after an elementary discussion of heat-treatment and the microstructure of spring steels, a considerable amount of space is devoted to fatigue. This does not include a good deal of information on the subject available in 1941; the work chosen for detailed discussion is that of Wöhler (about 1870) and of the author, at very low endurances (up to 70,000 cycles).

Indexes are included of subject, name and railway references.

D. G. SOPWITH.

BIBLIOGRAPHY

(Continued from pp. 25 A-26 A)

- AGEEV, N. V. "*The Chemistry of Metallic Alloys.*" Pp. 120. Illustrated. Moscow and Leningrad, 1941: Izdatel'stvo Akademii Nauk S.S.S.R. (Price 6 R. 35 k.) [In Russian.]
- ALLAN, R. K. "*Rolling Bearings.*" 8vo, pp. 402. London, 1945: Sir Isaac Pitman and Sons, Ltd. (Price 30s.)
- ALLPORT, N. L. "*Colorimetric Analysis.*" 8vo, pp. xii + 452. London, 1945: Chapman and Hall, Ltd. (Price 32s.)
- AMERICAN FOUNDRYMEN'S ASSOCIATION. "*Foundry Sand Testing Handbook.*" Fifth Edition. Pp. 135. Chicago, 1944: The Association.
- AMERICAN FOUNDRYMEN'S ASSOCIATION. "*Cast Metals Handbook.*" 1944 Edition. 8vo, pp. xii + 756. Illustrated. Chicago, 1944: The Association.
- BERG, L. G., A. V. NIKOLAEV and E. YA. RODE. "*Thermography: Heating and Cooling Curves.*" Pp. 175, illustrated. Moscow and Leningrad, 1944: Izdatel'stvo Akademii Nauk S.S.S.R. (Price 11 R.) [In Russian.]
- BRITISH STANDARDS INSTITUTION. B.S. 405: 1945. "*Expanded Metal (Steel) for General Purposes.*" 8vo, pp. 11. London, 1945: The Institution. (Price 2s.)
- BRITISH STANDARDS INSTITUTION. B.S. 163: Part 2, 1945. "*Galvanised Solid Steel Wire for Signalling Purposes.*" 8vo, pp. 9. London: The Institution. (Price 2s.)
- BRITISH STANDARDS INSTITUTION. B.S. 416: 1944. "*Cast Iron Spigot and Socket Soil, Waste and Ventilating Pipes, Fittings and Accessories.*" 8vo, pp. 44. Illustrated. London: The Institution. (Price 3s. 6d.)
- BRITISH STANDARDS INSTITUTION. B.S. 417: 1944. "*Galvanised Mild Steel Cisterns, Tanks and Cylinders.*" 8vo, pp. 18. Illustrated. London: The Institution (Price 2s.)
- BRITISH STANDARDS INSTITUTION. B.S. 460: 1944. "*Cast Iron Spigot and Socket Rainwater Pipes. Fittings and Accessories.*" 8vo, pp. 45. Illustrated. London: The Institution. (Price 3s. 6d.)
- BRITISH STANDARDS INSTITUTION. B.S. 482: 1945. "*Wrought Iron and Mild Steel Hooks for Cranes, Chains, Slings for General Engineering Purposes, Excluding Building Operations.*" 8vo, pp. 51. Illustrated. London: The Institution. (Price 2s.)
- BRITISH STANDARDS INSTITUTION. B.S. 1189: 1944. "*Cast Iron Baths for Domestic Purposes.*" 8vo, pp. 13. London: The Institution. (Price 2s.)
- BRITISH STANDARDS INSTITUTION. B.S. 1202: 1944. "*Wire Nails and Cut Nails for Building Purposes.*" 8vo, pp. 14. London: The Institution. (Price 2s.)
- BRITISH STANDARDS INSTITUTION. B.S. 1205: Part I: 1945. "*Cast Iron Gutters, Fittings and Accessories. Part I. Half Round Gutters.*" 8vo, pp. 9. Illustrated. London: The Institution. (Price 2s.)
- BRITISH STANDARDS INSTITUTION. B.S. 1211: 1945. "*Centrifugally Cast (Spun) Iron Pipes for Water, Gas and Sewage.*" 8vo, pp. 14. London: The Institution. (Price 2s.)
- BRITISH STANDARDS INSTITUTION. B.S. 1221: 1945. "*Steel Fabric for Concrete Reinforcement. Part A: Hard Drawn Steel Wire Fabric. Part B: Twisted Steel Fabric. Part C: Expanded Metal (steel) Fabric.*" 8vo, pp. 20. London: The Institution. (Price 2s.)

- "*Coal—Facts about an Unknown Industry.*" By a Colliery Manager. London: Chapman and Hall, Ltd. (Price 2s. 6d.)
- ETHERINGTON, H. "*Modern Furnace Technology.*" Second, revised edition. 8vo, pp. x + 524. Illustrated. London, 1944: Charles Griffin and Co., Ltd. (Price 34s.)
- FIELD, S., and A. D. WEILL. "*Electroplating.*" Fifth Edition, 8vo, pp. 482. London, 1945: Sir Isaac Pitman and Sons, Ltd. (Price 15s.)
- HALL, N., and G. B. HOGABOOM, jun. "*Plating and Finishing Guide Book, 1944.*" 13th edition. Pp. 228. New York, 1944: Metal Industry Publishing Co. (Price \$1.00.)
- HAYWOOD, F. W., and A. R. WOOD. "*Metallurgical Analysis by Means of the Spekker Photo-Electric Absorptiometer.*" 8vo, pp. xii + 128. Illustrated. London, 1944: Adam Hilger, Ltd. (Price 18s.) [See p. 71 A.]
- HESSE, H. C., and J. H. RUSHTON. "*Process Equipment Design.*" Pp. 580. Illustrated. New York: Van Nostrand. (Price \$7.50.)
- HOPKIN and WILLIAMS, Ltd. "*Organic Reagents for Organic Analysis.*" 8vo, pp. 172. London, 1944: Hopkin and Williams, Ltd. (Price 5s. 6d.)
- HOUGHTON, E. F., and Co. "*Practical Metallurgy for Engineers.*" 4th revised edition. Pp. 479. Philadelphia, 1943: The Company. (Price \$3.)
- HUDSON, R. G. "*An Introduction to Electronics.*" Pp. 97. Illustrated. New York: MacMillan Publishing Co. (Price \$3.)
- JACKSON, A. "*Amateur Photomicrography with Simple Apparatus.*" 8vo, pp. 156. Illustrated. London and New York, 1943: The Focal Press. (Price 7s. 6d.)
- MAINARDOS, M. "*I forni elettrici e le industrie elettrosiderurgiche, elettrometallurgiche, elettrochimiche, elettrotermiche, elettrolitiche.*" 2nd edition, pp. 617. Milan, 1943: U. Hoepli.
- MANTELL, C. L. "*Adsorption.*" 8vo, pp. viii + 386. New York, 1945: McGraw-Hill Book Co., Inc. (Price \$4.50.)
- MOLLOY, E. "*Power Presses.*" 8vo, pp. xxii + 202. London, 1945: George Newnes, Ltd. (Price 15s.)
- PASCHKIS, V. A. "*Industrial Electric Furnaces and Appliances.*" Vol. 1. Pp. 232. Illustrated. New York: Interscience Publishers, Inc. (Price \$4.90.)
- ROSKILL, O. W., and Co. (REPORTS), Ltd. "*Report on Refrigeration in the Engineering Industry.*" Folio, pp. xi + 69. London, 1944: The Company. [Mimeographed.]
- SAWYER, R. T. "*The Modern Gas Turbine.*" Pp. 216. New York: Prentice-Hall Company. (Price \$4.)
- SOCIETY OF CHEMICAL INDUSTRY. "*Reports of the Progress of Applied Chemistry.*" Vol. XXVIII, 1943. 8vo, pp. 517. London: The Society.
- SNELL, F. D., and F. M. BIFFEN. "*Commercial Methods of Analysis.*" Pp. 739. New York: McGraw-Hill Book Co., Inc. (Price \$6.)
- STAPP, H. "*Chemie der Metalle und Austauschwerkstoffe für technische Berufe.*" Pp. 110. Leipzig: J. Klinkhardt. (Price R.M. 2.20.)
- TRUBIN, K. G. "*Fundamental Problems Relating to the Quality of Steel Ingots.*" (Scientific Engineering-Technical Society of Metallurgists of the East. Steel-Casting Section.) Sm. 8vo, pp. 80. Sverdlovsk and Moscow, 1943. [In Russian.]
- WARNOCK, F. V. "*Strength of Materials.*" (Engineering Degree Series.) Sixth edition. 8vo, pp. 398. London, 1945: Sir Isaac Pitman and Sons, Ltd. (Price 12s. 6d.)
- YOUNG, C. B. F. "*Chemistry of Electroplating.*" Pp. 244. Brooklyn, N.Y.: Chemical Publishing Company. (Price \$4.)

MINERAL RESOURCES

(Continued from p. 27 A)

Coking Coal Resources of the Yorkshire, Nottinghamshire and Derbyshire Coal Field. R. A. Mott. (Midland Institute of Mining Engineers: Colliery Guardian, 1945, vol. 170, May 25, pp. 639-642; June 1, pp. 671-675; June 8, pp. 703-704). The large reserves of iron ore in the Lincolnshire, Northamptonshire, and Oxfordshire beds favour the continued expansion of the iron-making industry in the Midlands, but there is some doubt as to whether sufficient coking coal would be available. In this paper a method is described for the estimation of the coke-making character of the coal seams in areas where these seams have not yet been worked, and the geology of the seams in the South Yorkshire and North Midlands is examined by this method.

Summary of Bureau of Mines Exploration Projects on Deposits of Raw Material Resources for Steel Production. C. E. Julihn and L. B. Moon. (United States Bureau of Mines, Mar., 1945, Report of Investigations No. 3801). Brief reports are presented of the results of Bureau of Mines surveys of mineral deposits in the United States containing chromite, iron, manganese, tungsten, fluorspar, nickel, cobalt, molybdenum, vanadium, and coal, the object being to determine the tonnage and grade of the ores as a basis for mining operations.

Reserves, Bed Characteristics, and Coking Properties of the Willow Creek Coal Bed, Kemmerer District, Lincoln County, Wyo. A. L. Toenges, J. D. Davies, L. A. Turnbull, and J. M. Schopf. (United States Bureau of Mines, 1945, Technical Paper No. 673).

Mineral Resources of the World. D. Williams. (Advancement of Science, 1945, vol. 3, No. 10, pp. 206-221). The distribution and relative importance of the world's mineral resources are discussed under the following headings: (1) The geological control and geographical distribution of mineral deposits; (2) statistics of mineral production; (3) interdependence of nations on mineral supplies; (4) national self-sufficiency; (5) access to mineral supplies; (6) ore; (7) the discovery of mineral deposits; (8) the estimation and classification of ore reserves; (9) mineral resources of the world; (10) the importance of certain alloys and of minerals new to industry (11) scrap metals; (12) conservation of mineral resources; and (13) some international aspects of mineral resources.

ORES—MINING AND TREATMENT

(Continued from pp. 27 A-28 A)

Ore and Coal Handling on the Lower Lakes. A. E. Gibson. (Iron and Steel Engineer, 1945, vol. 22, May, pp. 77-83). The development of bridges for unloading ore from the Great Lake steamers and of tippers for unloading coal from railway trucks is described and illustrated.

Semi-Pilot-Plant Investigations of Nitrogen Dioxide Process for Beneficiation of Manganese Ores. A. L. Fox, A. E. Back, C. J. Chindgren, K. E. Tame, and D. Kaufman. (United States Bureau of Mines, 1945, Technical Paper No. 674). The Bureau of Mines published its first report on the use of nitrogen dioxide in the concentration of low-grade manganese ores in 1942. In the present paper an account of further investigations with a plant treating about 300 lb. of ore in 24 hr. is given.

Design and Operation of Modern Sintering Plants. C. J. Duby. (Iron and Steel Engineer, 1945, vol. 22, May, pp. 39-42). Five large sintering plants have recently been built by the Republic Steel Corporation. They are all of the continuous-pallet type. A detailed description of one of these plants at Warren, Ohio, is given. The pallet conveyor on the sintering machine is 6 ft. wide and 89 ft. long; it has a capacity of 30,000 tons of sinter per month.

A Rapid Method of Ore Testing. The "S.K." Porosity Test. H. L. Saunders and H. J. Tress. (Iron and Steel Institute, 1945, this Journal, Section I). An apparatus is described for the rapid determination of the porosity of ores by what is known as the "S.K." (South Kensington) test. The principle of the test is to fill the voids in turn with mercury, air, and water; for porous materials the voids are greatest for air, less for water, and least for mercury. The differences between the values are a measure of the porosity relative to the fluids employed. Several specimens of ore and sinter were examined. Ores are more porous than sinters, while the voids of mixtures are additive. It is shown how the measurements can be applied to forecast the behaviour of materials in the blast-furnace (deoxidation and carbon deposition).

Sinters and Sintering.—Part I. H. L. Saunders and H. J. Tress. (Iron and Steel Institute, 1945, this Journal, Section I. Sinter in the blast-furnace burden is beneficial in spite of its lower reducibility as compared with ore; hence any improvement in quality of the sinter would be reflected in fuel economy, provided it behaved similarly in preserving an open burden. In this connection differences in the behaviour of ore and sinter towards furnace gas are considered. Some of the changes occurring during the various stages of sintering are outlined, with special reference to the effect of temperature on porosity and strength. From a study of laboratory sinters prepared under controlled conditions, changes in texture have been followed, and it is shown that in usual commercial practice the bonding temperature is far too high, with the result that unnecessary slagging and loss of porosity result. The need for closer control is stressed, and various suggestions for modifications to existing plant are made.

FUEL

(Continued from pp. 29 A- 31A)

Heat-Transfer to Water-Cooled Furnace Walls. H. Kreisinger and R. C. Patterson. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, Furnace Performance Factors, pp. 71-78). The results of measurements of the transfer of heat to the water-cooled furnace walls of two boiler furnaces fired with pulverized coal are presented. The heat transfer was measured with small heat-absorbing units placed at different elevations in one of the walls of the furnace.

New Combustion-Control Methods for All Standard Fuels. R. Reed. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. 407-410). Suggestions are made for increasing the accuracy of combustion control in all types of furnaces and with all types of standard fuels either by recorded CO_2 concentrations, or by Orsat analysis of the flue gases. A simple apparatus for determining aldehydes in flue gases is described. The importance of combustion control for fuel economy and the elimination of furnace troubles is emphasized.

Ratio and Multiple-Fuel Controls in the Steel Industry. H. Ziebolz. (Transactions of the American Society of Mechanical Engineers, 1944,

vol. 66, pp. 705-711). The need for accurate control of the atmosphere in the steel furnace has led to the development of a variety of furnace designs and methods of fuel control. Systems of flow-meters, automatic proportioning valves and regulators for single and multiple gaseous fuels are described.

Selecting Gas Immersion Tubes. (Steel, 1945, vol. 116, June, pp. 108-110, 146, 148). Data on the design and applications of immersion-tube burners suitable for industrial heating purposes, worked out by the Committee on Industrial Gas Research of the American Gas Association, are presented, together with complete information on determining the heating efficiency.

Application of Gas Burner Equipment to Existing Furnaces. A. H. Koch. (Steel Processing, 1945, vol. 31, Mar., pp. 179-182). Data and formulæ are presented which facilitate the calculation of the amounts of gaseous fuel required and the burner capacity for heating metals in furnaces.

The Importance of the Ruhr Coking Industry. (Coke and Smokeless-Fuel Age, 1945, vol. 7, Apr., pp. 78-79). Statistics on the production and consumption of hard coke in the Ruhr district are presented and discussed. In each of the years 1939-1944 the production was 35,000,000 metric tons, and the amount produced in 1937 was about 80% of that produced in the whole of Germany.

Carbonizing Properties and Petrographic Composition of Hazard No. 4 Coal from Columbus No. 4 Mine and High-Temperature Carbonizing Properties of Hazard No. 7 Coal from Hardburly Mine, Perry County, Ky. J. D. Davis, D. A. Reynolds, W. H. Ode, C. R. Holmes, J. L. Elder, and J. E. Wilson. (United States Bureau of Mines, 1945, Technical Paper No. 672).

Anthracite Additions to Coke Oven Coal Mixtures for the Production of Blast Furnace Coke. D. L. Newkirk. (Blast Furnace and Steel Plant, 1945, vol. 33, Apr., pp. 461-463). Owing to the scarcity of low-volatile coal at the coke-ovens of the Ford Motor Co. trials were run with charges containing up to 6% of anthracite. Data on the effects of different charge mixtures on the screen analysis and properties of the coke produced, as well as on the coke consumption and iron production in the blast-furnaces, are presented and discussed.

Chemicals from Carbonisation Gases. I. The Separation of Methane and Ethylene. N. Booth. (Coke and Smokeless-Fuel Age, 1945, vol. 7, May, pp. 85-87). The possible sources of additional quantities of methane and ethylene in Great Britain are reviewed. It is suggested that quite large quantities of methane could be got from coke-oven gas and moderate amounts from town's gas; at the same time the ethylene in the gas might be recovered. The separation of methane and ethylene from carbonization gases by adsorption, solvent extraction, liquefaction, and thermal diffusion is considered.

PRODUCTION OF IRON

(Continued from [p. 31 A])

History of the Development of the Blast Furnace in Great Britain. H. E. Wright. (Cleveland Institution of Engineers: Iron and Coal Trades Review, 1945, vol. 150, May 18, pp. 733-736; May 25, pp. 777-780). A comprehensive account of the development of the blast-furnace in Great Britain is presented, the various improvements which brought its efficiency to its present high level being discussed in chronological order. Blowing power and hearth diameter are more important than stack lines and profiles

in determining the furnace output. There appears to be no alternative to blast-furnaces and steel-making plants for meeting existing and future requirements.

The Fused-Salt Electrolysis for the Production of Metal Powders. W. J. Kroll. (Electrochemical Society, Apr., 1945, Preprint No. 5). The demand for metal powders of high purity for the powder-metallurgy process has suggested their production by the fused-electrolyte method. When the melting point of the metal is above the bath temperature the metal will be deposited as small crystals or as dendrites. About twenty metals have, according to the literature, been deposited in this form. The advantages of operating at lower bath temperatures and of getting a solid rather than a liquid product is offset by the difficulty in eliminating the entrained or adherent fused salt from the metal crystals. Methods of overcoming this are discussed. In the case of refining iron by anodic dissolution in an alkali-chloride bath, carbon, silicon, sulphur, and phosphorus are eliminated. The iron product obtained is very pure, soft, and free from nitrogen and hydrogen; it is dense, sharp-edged, free-running, and of a grain size suitable for powder metallurgy.

Metal-Powder Friction Materials. C. S. Batchelor. (Metals and Alloys, 1945, vol. 21, Apr., pp. 991-993). The manufacture of brake-blocks, clutch-plates, and other parts subjected to great friction from mixtures of powdered copper, tin, lead, iron, graphite, alundum, silica, and carborundum by the powder-metallurgy process is described.

Powder-Metal Parts. G. W. Birdsall. (Steel, 1945, vol. 116, Apr. 16, pp. 106-108, 150-158). Brief descriptions are given of a great variety of parts which have been successfully produced by the powder-metallurgy process. Improvements in technique have enabled the process to be applied to parts weighing as much as 90 lb.; bearings 18 in. in dia. have been made.

FOUNDRY PRACTICE

(Continued from pp. 50 A-53 A)

A New Method of Investigating the Behaviour of Charge Material in an Ironfoundry Cupola and Some Results Obtained. N. E. Rambush and G. B. Taylor. (Institute of British Foundrymen, 42nd Annual Meeting, June, 1945, Paper No. 826). Owing to the changes in the pig-iron charged into a cupola, irregularity in the carbon content of the melt was experienced and it was decided to investigate the physical conditions existing in a cupola by the novel method of shutting off the blast and pouring in water on top of the burden through the charging door. This was done without danger to the operators, and the charge was rendered inert by water-cooling in less than 40 min. A few hours later the charge was removed piecemeal from the top downwards. From the appearance and position of the coke and of previously drilled pieces of pig-iron and steel, a picture of the cupola process was built up, with special reference to the absorption of carbon by the steel. The following conclusions were reached: (1) However carefully the charge materials are placed in a cupola in relation to one another, their original relative position is not maintained during the descent of the charge; (2) the shape and size of the metallic pieces in the charge are dominant factors governing their manner of descent; (3) where different qualities of metal are to be produced during the day's heat, the influence on "dilution" caused by factors (1) and (2) is of great importance; (4) the rate of complete melting of the metal pieces is mainly governed

by their shape and weight as well as by their relative melting temperatures; (5) metallic constituents that require a longer time to melt than others may not be melted completely until they have descended into the coke-bed to a considerable depth; (6) the coke, although evenly sized to start with, becomes progressively smaller from top to bottom of the shaft; this applies to both bed and charge coke; (7) the weight of layers of coke at different levels in the cupola increases as the charge moves downwards; (8) the reduction in coke size in the bed proper is not uniform across a horizontal plane, the coke in the centre being reduced the most, whilst that against the walls remains almost unaffected; (9) the coke remaining below the tuyere level is reduced most in size from the original, probably because of intermittent exposure to direct burning; (10) the extent of the slag ledge or bridge formed above the tuyere level is a main factor altering the line of flow of materials through the cupola as the day's heat proceeds; (11) the carbon content of the steel test-bars (marked by drilling) increases very slightly in their downward travel when solid, but on the commencement of melting, the carbon absorption becomes much more rapid; (12) the melting steel absorbs carbon chiefly at the surface, the centre remaining practically unaltered; the highest carbon content found in a solidified drop of metal was 1.2%; (13) some of the carbon picked up by the steel remains graphitic in nature; (14) the steel in the charge picks up sulphur rapidly on its surface shortly after its introduction into the cupola, but some of this sulphur seems to be given off again as the steel descends the cupola.

Consistency and the Cupola. C. A. Payne. (Institute of British Foundrymen: Foundry Trade Journal, 1945, vol. 76, June 7, pp. 111-117; June 14, pp. 133-137). A comprehensive review of the factors affecting the control of cupola melting is presented. The subject is dealt with under the following headings: (1) Cupola design; (2) tuyere arrangement; (3) lining contour; (4) maintenance; (5) taphole practice; (6) drying out; (7) raw material; (8) coke control; (9) blast control; (10) coke weight and air supply; (11) charging practice; (12) control of air supply; (13) operational details; (14) care in piking; and (15) timing of operations.

Preliminary Investigation of Metal Pouring by Ciné Radiography. S. L. Fry. (Institute of British Foundrymen, 42nd Annual Meeting, June, 1945, Paper No. 821). A description is given of the development of a suitable technique for taking cinematograph pictures of a fluorescent screen on which radiographs of molten metal entering a mould were projected. Full details of the X-ray projector, mould, screen, cinema camera, and developing technique are given. Some examples of the pictures produced at 16 and at 64 frames per sec. of the fast and slow pouring of lead are reproduced. The great possibilities of the technique for investigations in the foundry are indicated.

Plant Modernization Increases Malleable Production. W. G. Gude. (Foundry, 1945, vol. 73, May, pp. 102-105, 230-232). A description is given of the plant and processes at the malleable iron foundry of the Belle City Malleable Iron Co., in Wisconsin, where two new 5-ft. dia. cupolas and two air furnaces for duplex melting have been installed.

Production of Whiteheart Malleable Iron by Annealing in Partially Burnt Town's Gas. I. Jenkins and S. V. Williams. (Institute of British Foundrymen, 42nd Annual Meeting, June, 1945, Paper No. 824). Experiments are described in which whiteheart malleable cast iron was successfully annealed in an atmosphere produced by burning town's gas with twice its volume of air. The experimental work proved that the process is economic and suitable for use on an industrial scale; furthermore, under properly controlled conditions, the annealing time is considerably less than that necessary with the ore-annealing process, and all the difficulties associated with handling the ore are obviated.

The Annealing of Whiteheart Malleable Iron by a Gaseous Process. A. G. Robiette. (Institute of British Foundrymen, 42nd Annual Meeting, June, 1945, Paper No. 825). The theory and practice of the annealing of whiteheart malleable cast iron in an atmosphere of partially burnt coal gas is discussed. It is possible to work a short-cycle process using gas because: (1) The heating and cooling cycles are only a fraction of the times required in a packing process; (2) the temperature can be 70–100° C. higher in the gas process; (3) the gaseous decarburizing medium never becomes spent, as it may do in the ore process; and (4) very little margin of safety need be allowed in assessing the time the castings are up to temperature. In the process described, which was fully developed for use on an industrial scale, the gas is regenerated by mixing with sufficient air to reconvert the carbon monoxide to the original CO/CO₂ ratio, and similarly, the hydrogen to the correct H₂/H₂O ratio; thus, the furnace acted as a producer, producing, with the controlled air addition into the system, the correct atmosphere from the carbon in the castings. In practice, a make-up of gas has to be supplied to balance the losses from the system. By fitting a regeneration system to a furnace annealing 15 cwt. of castings per charge, the amount of raw coal gas used was reduced from 450 to 150 cu. ft./hr.

Blackheart Malleable Iron Castings Used on New Sydney Graving Dock. (Metallurgia, 1945, vol. 32, May, pp. 7–8). Production methods which have been developed to increase the size of malleable castings are described; more particularly, examples of the application of blackheart malleable cast iron to the production of large and heavy castings are given.

Boron in Malleable Iron. N. F. Tisdale. (Foundry, 1945, vol. 73, Apr., pp. 107, 222). The addition of boron to malleable cast iron is discussed. In the duplex process it is best to add ferro-boron to the stream of metal leaving the cupola spout. As the optimum addition is only 0.001–0.003% of boron, it is very difficult to add the requisite amount and obtain even distribution in a small ladle of metal. The time of the malleablizing treatment can be shortened when there is boron in the metal, but the amount to add has to be determined for each plant.

Controlled Spheroidization of Pearlitic Malleable Iron. C. R. Wiggins. (Iron Age, 1945, vol. 155, May 10, pp. 78–81). The mechanism of short-cycle malleablizing is discussed, and the practice in the production of "Z-Metal" (a white iron containing some combined carbon in the spheroidized form) is reviewed. A spheroidization chart is presented that could serve as a standard of spheroid particle size for other ferrous materials, such as steels.

The Gating and Feeding of Steel Castings. S. T. Jazwinski, E. D. Wells, and S. L. Finch. (Institute of British Foundrymen, 42nd Annual Meeting, June, 1945, Paper No. 829). Five main factors affect the feeding of castings; these are time, temperature, mass, analysis of metal, and pressure. The supply of liquid steel from a feeder head is considered, and the solidification of gravity, whirlgate and atmospheric heads is studied. A head 3.5 in. in dia. and 8 in. high is the right size to feed a 4-in. cube; any reduction in the diameter or height causes a shrinkage cavity in the cube. The application of graphite and carbon rods in feeder heads was investigated. The distribution of the carbon and the feeding efficiency were determined, and from the results obtained it can be said that the use of these rods is not an economical proposition.

An Investigation of the Constitution of Certain Foundry Bonding Clays. R. W. Grimshaw and A. L. Roberts. (Institute of British Foundrymen, 42nd Annual Meeting, June, 1945, Paper No. 822). Some of the methods available for the identification and estimation of the principal constituent minerals in clays are briefly described. With these methods the constitu-

tion of a particular foundry bonding clay (Colbond) was studied in detail.

A Study of Moulding Methods for Sound Castings. F. G. Sefing. (Institute of British Foundrymen, 42nd Annual Meeting, June, 1945, Paper No. 828). See p. 52 A.

Casting and Machining Iron Crankshafts. J. G. Bergdoll. (Metals and Alloys, 1945, vol. 21, Apr., pp. 994-999). A description of the casting of iron crankshafts for compressors is given.

Precision-Cast High-Speed Steel. (Machinery, 1945, vol. 66, June 14, pp. 641-647). An illustrated description is given of the process developed by the Ford Motor Company for casting milling cutters in high-speed steel with such accuracy that only grinding to sharpen the cutting edges is required. A master pattern of steel or bronze is first made, and this is used for making duplicate patterns in wax. The final mould enclosing the wax pattern is made of a mixture of materials such as oxides of aluminium, magnesium, and zirconium with a binder. This mould is heated in an oven to melt out the wax. The high-speed steel is melted in a 15-lb. carbon-arc furnace and poured into the cavity left by the wax.

Casting Tool Steels Centrifugally. (Steel, 1945, vol. 116, June 4, p. 112). The process of the centrifugal casting of high-speed cutting tools of the tungsten-cobalt type is described.

Centrifugal Casting of Steel. S. D. Moxley. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. 607-613). The author gives comprehensive descriptions of true centrifugal casting (for hollow cylindrical bodies), semi-centrifugal casting (for flywheels and the like), and centrifuging (for casting clusters of similar parts evenly spaced round the mould axis through which the metal is fed). Details are given of the machines used and of the physical properties of the products.

Operates Big Shop in Small Town. P. Dwyer. (Foundry, 1945, vol. 73, Apr., pp. 110-112, 240-244). A description is given of the equipment and processes at a large iron foundry in Fremont, Ohio, where sections of low-pressure boilers are made.

Initial Experience in Hydraulic Cleaning in a Steel Foundry Fettling Shop. F. N. Lloyd. (Institute of British Foundrymen, 42nd Annual Meeting, June, 1945, Paper No. 820). A comprehensive account of the Hydro-Blast process of cleaning sand from castings and of dewatering and screening the recovered sand, as practised at a Wednesbury foundry, is presented. Data on the costs of the process are also given. Sand which has passed through the process differs slightly in mechanical grading from new sand, and mixtures prepared from it are not quite so strong as those prepared with new sand, probably because of the carbonaceous deposit on the Hydro-Blast sand grains; this can be made good by a slight increase in the amount of the bonding materials.

Design Features of Conveying Equipment for the Foundry Industry. F. B. Henry and G. N. Wileman. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. 235-246). Conveyors used in American foundry practice are described. Special consideration is given to plant for the economic handling of sand, moulds, and castings; this results in savings in production costs.

PRODUCTION OF STEEL

(Continued from pp. 53 A-55 A)

Some Recent Trends in Steel Manufacture. G. A. V. Russell. (Proceedings of the Cleveland Institution of Engineers, 1941-42, No. 3, pp. 71-97). See Journ. I. and S.I., 1942, No. II., p. 51 A.

Dolomite Fettling Machine. (Iron and Coal Trades Review, 1945, vol. 150, June 29, pp. 979-980). A description of the "Blaw-Knox" fettling machine for repairing the walls of open-hearth furnaces with dolomite is given. With this machine a furnace can be made up, front and back, in about 8 min.

Vacuum System Removes Dust from Open-Hearth Flues. (Steel, 1945, vol. 116, June 4, p. 125). Dirt from open-hearth furnace flues is conveyed by suction through a steel collecting drain to a receiving tank which empties into a box or truck. Savings in man-hours are claimed to range from 50% to 70%.

Controlling Gases in Open Hearth Steel. A. F. Whalen and J. Nagy. (Blast Furnace and Steel Plant, 1945, vol. 33, Apr., pp. 46-48, 76). The method of controlling open-hearth furnace heats at the works of the Harrisburg Steel Corporation is described. Small ingots 4 in. high, $1\frac{1}{2}$ in. square at the base, and 2 in. square at the top are poured from time to time, and slag buttons are cast. The sample ingots are sectioned and the amount of gas is judged from the appearance of the section.

An Analysis of Open-Hearth Combustion. G. E. Seil. (Steel, 1945, vol. 116, May 14, pp. 124, 172-180). The ideal flame and combustion conditions in an open-hearth furnace are discussed. A system of burners in the front and back walls providing flames across the furnace is described and its advantages and disadvantages are considered.

Proceedings of the Second Electric Furnace Steel Conference. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, Oct. 5-6, 1944, vol. 2). The Second Annual Conference on Electric Furnace Steel sponsored by the Electric Furnace Steel Committee, Iron and Steel Division of the American Institute of Mining and Metallurgical Engineers, was held at Pittsburgh. The Conference was divided into five sessions on the following subjects: (1) Performance and Maintenance of Equipment for Electric Arc Furnaces; (2) Refractories; (3) Melting and Oxidizing; (4) Refining, Deoxidizing, and Pouring; and (5) Control of Bath Composition.

After the introductory speeches the following papers were presented and discussed in the first session:

Problems in the Effective Use of Power in Production of Electric-Furnace Steel, by L. W. Long.

Maintaining Mechanical and Auxiliary Equipment to Minimize Delays, by A. J. F. MacQueen.

Handling and Proper Use of Electrodes, by A. Kaul.

Maintenance of Mechanical and Electrical Equipment for Arc Furnaces, by W. B. Ferguson.

The following papers were read in the second session:

Care and Handling of Refractories, by H. M. Parkhurst.

Direct-Arc Electric-Furnace Roofs, by E. K. Pryor.

Basic Furnace Bottoms and Construction, by H. C. Bigge.

The remainder of this session was taken up with brief discussions of sillimanite roofs, factors affecting the roof life of large and small furnaces, silica roofs, roof design and maintenance, and basic side walls and bottoms.

The third session consisted of the five papers on basic furnace practice enumerated below, followed by discussions on controlling residual chromium, working heats of chromium steel, and sulphur removal :

- Use of Power for Fast Melting**, by N. J. Roberts.
- Control of Carbon at Melting**, by L. H. Nelson.
- Control of Carbon at Meltdown**, by A. C. Texter.
- Control of Carbon at the Meltdown**, by H. C. Bigge.
- The Function of a Reboil**, by A. Blough.

The fourth session, also on basic furnace practice, consisted of three papers and a discussion on pouring and mould practice. The three papers were :

- Slag-Metal-Oxygen Relationships in the Basic Open-Hearth and Electric Processes**, by J. S. Marsh.
- A Method for the Determination of Bath Temperature**, by L. F. Weitzenkorn.
- Clean Steel**, by W. M. Farnsworth.

The fifth session on acid furnace practice began with discussions on rapid sampling and determining carbon by hardness, followed by the seven papers given below with an additional discussion on controlling the carbon :

- Determination of Carbon by the Fracture Method**, by C. C. Spenser.
- Introduction to Magnetic Methods for the Determination of Carbon Content of a Steel Bath**, by C. Locke.
- Determination of Carbon by the Carbanalyzer**, by E. C. Troy.
- Determination of Carbon by Chemical Methods**, by E. C. Conary.
- Determination of Total Carbon in Cast Iron, Steel, Ferroalloys and Nonferrous Alloys**, by M. F. Milligan.
- Determination of Aluminium in Acid Steel**, by R. A. Willey.
- Survey of Available Methods for the Determination of Residual Aluminium in Steel**, by R. M. MacIntosh.

The sixth session, also on acid furnace practice, began with discussions on the control of gases in molten metal and the procedure for adding deoxidizers, after which the following papers were presented :

- Grain-Size Control in the Foundry**, by J. B. Caine.
- Lime in Acid Slags**, by C. E. Sims.

Electric Furnace Capacity. J. McBroom. (Foundry, 1945, vol. 73, Apr., pp. 115, 235-236). Data and curves are presented which facilitate the rapid calculation of the capacity of electric furnaces.

Some Methods of Establishing and Enforcing Control of Surface Quality. H. J. Forsyth. (Blast Furnace and Steel Plant, 1945, vol. 33, Apr., pp. 455-460). Methods of maintaining a high standard of surface quality on steel billets are discussed, and data are presented relating the man-hours spent on surface cleaning (by chipping, grinding, or flame-scarfing) to ingot-mould preparation and life, and to soaking-pit practice.

Ladle Deoxidation in Steel Production. (Blast Furnace and Steel Plant, 1945, vol. 33, Apr., pp. 469-474). The degree of cleanliness and the grain size of steel billets and bars obtained when steel is deoxidized in the ladle with an alloy called "Simanal" (containing silicon 20%, manganese 20%, aluminium 20%, and iron 40%) are discussed.

FORGING, STAMPING, AND DRAWING

(Continued from pp. 55 A-56 A)

Flow-of-Metal Aspects of Shell-Forging. M. D. Stone. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, Forging of Steel Shells, pp. 1-9). The flow metal in the piercing of shells, the shape of the dies and mandrels, and the forces involved in the operations are discussed.

Forces Acting in the Piercing of Cylinders. W. Trinks. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, Forging of Steel Shells, pp. 11-14). Formulæ are derived for calculating the force required on the mandrel for the forging of hollow cylindrical (or almost cylindrical) bodies.

Experimental Study of Shell Drawing. G. Sachs and G. B. Kasik. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, Forging of Steel Shells, pp. 15-30). An investigation of the effects of the following factors on the process of piercing shells is described: (1) Reduction in the cross-sectional area; (2) die angle; (3) cavity shape; (4) mandrel shape; (5) wall thickness; (6) base thickness; (7) lubrication; and (8) speed of piercing.

Plastic States of Stress in Curved Shells: The Forces Required for Forging of the Nose of High-Explosive Shells. A. Nadai. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, Forging of Steel Shells, pp. 31-44).

An Experimental Investigation of the Nosing of Shells. R. K. Carlson. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, Forging of Steel Shells, pp. 45-55). An investigation is described which was designed to show the effects of temperature, lubricating, and speed on the process of nosing shells.

Forging and Heat Treating Shell and Ordnance Parts at Oldsmobile. (Industrial Heating, 1945, vol. 12, Apr., pp. 567-582). A description is given of the sequence of processes at a works at Lansing, Michigan, where billets are induction-heated to 2300° F. and pierced in six stages into hollow 105-mm. shells. In the subsequent heat-treatment operations, which are described and illustrated, a high degree of mechanization has been achieved.

Drawing Thin-Walled Tubing with a Moving Mandrel through a Single Stationary Die. G. Sachs, J. D. Lubahn, and D. P. Tracy. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. A199-A210). The fundamental equations for the drawing of tubing with a moving mandrel have been solved for the simplified cases of both cold-drawing and hot-drawing of thin-walled tubing through a stationary die. Various solutions were developed for any contour of the dies and any shape of the stress-strain curve. The effects of the die and punch contours and of the coefficients of friction between the metal and the die and punch on the stresses in the metal, the drawing forces, and the limits of drawing were determined. With a small die angle, and high friction on the mandrel, the process resembles extrusion rather than drawing, the limit being determined by the strength of the die instead of by the tensile strength of the metal.

Theory of Wire Drawing. E. A. Davis and S. J. Dokos. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. A193-A198). A theory of wire drawing is presented by which the force required to produce plastic deformation of a wire passing through

a die may be determined. The calculations are based on information obtained from an ordinary tensile test of the material to be drawn.

New Wire Rewinding Equipment Triples Production. P. Somerville, L. R. Hunt, and J. D. Campbell. (Steel, 1945, June 11, pp. 144-147, 192). Details of the design of a wire-rewinding plant are described. Mechanical improvements and the adoption of electronic control of the drive resulted in an increase in the speed of the wire to the bobbins. The new and old methods of bobbin winding are compared.

ROLLING-MILL PRACTICE

(Continued from pp. 37 A-38 A)

Demulsifiers in Circulating Oil Systems. T. G. Roehner and E. S. Carmichael. (Iron and Steel Engineer, 1945, vol. 22, May, pp. 62-66). Lubricating oil for rolling mills becomes contaminated with water and forms an emulsion which it is sometimes difficult to break down by settling or centrifuging. This difficulty may be due to the presence of an adsorbed film on the globules of water which retards or prevents coalescence; in such case a demulsifying agent may be added before centrifuging to break down this film. The use of such agents is discussed.

Some Design and Operating Features of a New Blooming Mill. G. A. V. Russell and G. W. Fox. (Iron and Steel Institute, 1945, this Journal, Section I). The paper discusses the design and operating features of a new 43-in. reversing blooming-mill installation which has replaced a lighter mill at the Templeborough plant of The United Steel Companies, Ltd. Allusion is first made to the general layout of the plant and then the mechanical design of the new mill is considered, the mill train, main tables, and manipulator being dealt with in turn. The roll design and rolling practice adopted are next described, and some results of actual performance are included. The paper concludes with reference to certain improved auxiliaries which have been installed, such as a four-way hot-bloom descaler and a new type of preheating pit furnace for ingots.

Hawarden Bridge Steelworks of John Summers & Sons, Limited. (Iron and Coal Trades Review, 1945, vol. 150, Mar. 9, pp. 357-362). An illustrated description is given of the steelworks of John Summers and Son, Ltd., at Shotton, special reference being made to the rolling mills, which consist of a steam-driven slabbing mill, a spreader mill, and the finishing mill, which consists of five electrically-driven stands in tandem. There are also continuous pickling lines and annealing furnaces.

Seamless Tubes Made in Mill of Latest Design at Plant of Pittsburgh Steel Company. (Blast Furnace and Steel Plant, 1945, vol. 33, Apr., pp. 464-468). **New Seamless Tube Mill for Pittsburgh Steel.** (Iron and Steel Engineer, 1945, vol. 22, Apr., pp. 78-81). The new Mannesmann tube mill at the works of the Pittsburgh Steel Company is described (*see* p. 38 A).

Works of the New Jarrow Steel Company. (Iron and Coal Trades Review, 1945, vol. 150, June 22, pp. 929-932). An illustrated description is given of the rolling mills of the New Jarrow Steel Company where billets 30 ft. long and from 2 to 4 in. in dia. are rolled into sections, and slabs are rolled into strip.

The Amplidyne Generator from an Application Standpoint. J. D. Campbell. (Iron and Steel Engineer, 1945, vol. 22, May, pp. 54-60). An explanation of the principles of the amplidyne D.C. generator is given, and some of its applications in the control of rolling-mill motors are described.

The Theory and Design of Electronic Control Apparatus. W. D. Cockrell. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. 249-258). The almost infinitely fast and inertialess electronic tube can supplement mechanical control to produce many results hitherto considered impossible. Fundamental conceptions of the electronic tube are outlined, the types of tubes used are described, and practical applications of electronics to standard control circuits are indicated. Examples of such controls are the photo-electric relay, electronic timer, motor control, resistance welding, and photo-electric register control.

Application of Electronic Control. E. H. Vedder. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. 259-264). Electronic control is claimed to work faster, more precisely, and less expensively in a variety of applications. Among those described in this paper, the following are of interest: Motor control including an adjustable-speed drive for D.C. motors, a speed regulator, resistance welding apparatus, control units for "flowing" tin on coated strip in continuous tinplate mills, and the detection of pinholes in the tin coatings on strip.

HEAT-TREATMENT

(Continued from pp. 56 A-58 A)

Heat Treatment of Steel. A. Dubé and S. L. Gertsman. (Canadian Institute of Mining and Metallurgy: Canadian Metals and Metallurgical Industries, 1945, vol. 8, Apr., pp. 20-27). This paper presents some of the new concepts in physical metallurgy as regards heat-treatment of steel. Hypotheses advanced in the past as an explanation for the phenomena occurring in heat-treated steel have been replaced by scientific knowledge capable of coherently rationalizing the facts. Thus, greater attention to heat-treatment processes has been given by managements, and has led to a reduction in heat-treatment time with consequent increase in production, and to new control methods which permit the exacting specification requirements to be met more readily. Fifty-three references are given.

Probable Post-War Trends in Heat-Treatment. A. Glynne Lobley. (Metallurgia, 1945, vol. 32, May, pp. 15-19). Some of the directions in which heat-treatment will probably develop are discussed. It is shown how modern furnaces can assist in production.

Continuous Heat Treatment of Shells. D. E. Wyman. (Metals and Alloys, 1945, vol. 21, Apr., pp. 1009-1012). A large automatic installation for the continuous heat-treatment of shells is described.

Hardening "Moly" Hacksaw Blades. G. W. Birdsall. (Steel, 1945, vol. 116, May 21, pp. 109-110). A new method of heat-treating molybdenum-steel hacksaw blades is described. An inert atmosphere, which does not break down at the high temperatures employed (about 2300° F.), surrounds the charge in the furnace to prevent decarburization.

Heat-Treating High-Speed Steels. H. E. Lewis. (Steel Processing, 1945, vol. 31, Mar., pp. 159-163, 186; Apr., pp. 222-228). The equipment and procedure for the heat-treatment of the following high-speed steels are described: (1) 18/4/1 tungsten-chromium-vanadium steel; (2) 8.5/1.5/4/1 molybdenum-tungsten-chromium-vanadium steel; and (3) 5.75/4.5/4/1.5 tungsten-molybdenum-chromium-vanadium steel. Special attention is given to means of preventing decarburization.

Hard Surfaces on Steel by Induction Heating. J. L. Aston. (Metallurgia, 1945, vol. 32, May, pp. 24-30). A summary of the literature on the subject of the induction hardening of steel is presented and twenty-five

references are given. Subjects covered include high-frequency generators, supplementary equipment, concentrators, applications of surface hardening, metallurgy and technique of induction hardening, quenching, uneven heating, temperature measurement, heating of convex and concave surfaces, and efficiency.

Continuous Hardening of Steel Bars by Induction on a Commercial Basis. (Industrial Heating, 1945, vol. 12, Apr., pp. 610-618). A description is given of the induction heat-treatment plant at the works of the Caterpillar Tractor Co. of Peoria, Illinois, with which steel bars from $\frac{1}{2}$ in. to $1\frac{1}{4}$ in. in dia. can be rapidly hardened and tempered. Bars $\frac{7}{8}$ in. in dia. pass through a sodium-phosphate cleaning process and then through the first heating coil at a speed of 22.8 in. per min. As the bar leaves the coil it is quenched in a cone of water held at 80-90° F. Finally, it passes through the second coil for tempering at 1125° F.

Flame Hardening of Sprockets. (Machinery, 1945, vol. 66, June 21, pp. 669-674). A detailed description is given of the methods applied in the flame-hardening of the teeth of drive sprockets for military tanks. The life of a flame-hardened sprocket is three to four times that of an unhardened sprocket. Two methods are in use for this kind of work: Spot hardening and progressive hardening. Spot flame-hardening, as the most successful method in general use, is dealt with in detail.

Localized Annealing and Hardening. J. E. Hyler. (Steel, 1945, vol. 116, June 11, pp. 134-136, 180-184). Machines are described, employing gas or electricity, for the application of heat to certain areas of parts which are to be protected against wear, or are to retain or increase their softness. It is claimed that these machines are very adaptable for large-scale production methods. Details of their design and operation are given.

Effect of Grain Size and Subzero Treatment on Productivity of Four High-Speed Steels. S. M. Depoy. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. 645-648). The effect of grain size and sub-zero cold-treatment on the life of four high-speed steels was studied by means of a series of lathe tests on one alloy steel of a selected uniform hardness. Standard and sub-zero treatments were used at different hardening temperatures to develop different grain sizes and microstructures. The results show that the grain size, carbide solution, and type of martensite formed in the tool have a marked effect on its cutting ability. Sub-zero treatment is apparently much more effective when large grain sizes are developed.

Sub-zero Treatment of Steels. H. C. Amtsberg. (Canadian Metals and Metallurgical Industries, 1945, vol. 8, Apr., pp. 33-36). The paper presents the fundamentals of cooling hardened steels to temperatures considerably below room temperature and correlates them with the basic hardening treatment and the changes in microstructure. The value of sub-zero treatment is apparent in the improvement of properties and performance—particularly of tools—and in the partial cure for improper initial heat-treatment. Several curves illustrate time-temperature transformations, and time-temperature cycles as used in practice for various steels.

Individual Oil Quenches for Machine Parts. A. R. Hotchkiss. (Steel, 1945, vol. 116, June 14, pp. 122, 156). A pressure quench method is described which combines the advantages of a mild quenching medium with that of securing improved physical properties such as hardness. A single operation replaces a more complicated one, and leads to increased production.

Bibliography on the Burning and Overheating of Steel. (Iron and Steel Institute, 1944, Bibliographical Series, No. 10).

Bibliography on Quenching Media. (Iron and Steel Institute, 1945, Bibliographical Series, No. 11).

WELDING AND CUTTING

(Continued from pp. 58 A-61 A)

Weldability of Manganese-Silicon High Tensile Steels. G. G. Luther, F. H. Laxar, and C. E. Jackson. (Welding Journal, 1945, vol. 24, Apr., pp. 245-S-254-S). The results of weldability tests on forty-eight experimental manganese-silicon steels are presented and compared with the results of similar tests on a mild steel and eighteen commercial high-tensile manganese steels with and without additions of titanium or vanadium. The weldability of the manganese-silicon steels without titanium or vanadium was superior to that of manganese steels without additions and compared favourably with that of manganese steels with additions of titanium or vanadium.

A Study of the Tensile Properties of Heavy, Longitudinally Welded Plate Specimens Simulating Deck and Shell Joints. L. C. Bibber. (Society of Naval Architects and Marine Engineers: Welding Journal, 1945, vol. 24, Apr., pp. 193-S-226-S). An extensive investigation is reported in which tensile tests were made on large welded structures of $1\frac{1}{4}$ -in. steel plate which were designed to simulate types of joint used in the construction of cargo vessels and tankers. The following conclusions were reached: (1) Good strength and elongation can be obtained in longitudinally welded joints of heavy plates; (2) a square type of fracture is almost always obtained from welded joints pulled longitudinally; (3) a sharp square fracture does not indicate the absence of ductility in the steel; (4) small round blowholes in the weld reduce the tensile strength of the structure only slightly, but they may cause a considerable reduction in the elongation; and (5) the careless striking of arcs on heavy plate in cold weather can cause serious local increases in hardness, which may give rise to cracking and failure.

The Weld Stress Problem. (Welding Journal, 1945, vol. 24, June, pp. 313-S-319-S). The factors leading to the formation of stresses after welding are briefly reviewed. To evaluate these factors it is necessary to distinguish between the transient conditions and those which prevail when the structure has cooled to the ambient temperature. From the welding aspect the aim is to produce a joint free from flaws, cracks and undesirable metallurgical structures; the conditions conducive to this are considered by breaking the problem down into its essential elements, which are: (a) Stress raisers; (b) quality of steel; (c) service at low temperatures; (d) strain ageing; (e) rigidity; and (f) residual stresses.

Flash Welding 4130 Steel. W. W. Ackerman and W. Pestrak. (Welding Journal, 1945, vol. 24, May, pp. 463-467). See p. 12 A.

Low-Temperature Joining. R. D. Wasserman and C. E. Swift. (Welding Journal, 1945, vol. 24, May, pp. 449-453). The technique of welding ferrous and non-ferrous metals at temperatures below the melting point of the parent metal is described.

Conveyorized Welding of Hardenable Steel. C. W. Handova. (Iron Age, 1945, vol. 155, May 24, pp. 53-55, 130). A description is given of a conveyor line with eight welding stations for the mass production of the special treads required for amphibious tanks.

Which Carbon Steel for Arc Welding? W. J. Conley. (Metals and Alloys, 1945, vol. 21, Apr., pp. 1006-1008). The composition of steels suitable for particular types of welded joint is discussed.

Hardfaced Dies. M. Riddihough. (Iron and Steel, 1945, vol. 18, June, pp. 189-190). The technique is described for welding and hardfacing dies of 0.4% carbon steel with Stellite in order to prolong their life.

Unusual Applications of Gas Cutting to Ordnance Fabrication. C. M. Underwood. (Welding Journal, 1945, vol. 24, Apr., pp. 365-377). Descriptions are given of oxy-acetylene cutting machines and their application for the cutting of gun mountings, traversing rings, and other ordnance parts.

Electronic Flame Cutter. (Steel, 1945, vol. 16, May 28, pp. 102-104, 144). A new method is described by which the movements of cutting torches on contour work on steel plate are controlled by plastic records on drums which convey the prescribed curves to the driving gear by a scanning device containing photo-electric cells. The records are prepared by placing a drawing on the steel plate. A pointer, substituted for the burning torch, is guided by push-button control along the curve to be cut and a recording is made of the actions of two drive motors needed to follow the desired contour.

PROPERTIES AND TESTS

(Continued from pp. 63 A-68 A)

Metallurgy and Design. H. L. Lexier. (Canadian Metals and Metallurgical Industries, 1945, vol. 8, May, pp. 25-29). Various methods of reducing the large factors of safety which are in many cases employed are indicated; these are based on the exact measurement of stress and its distribution. Close co-operation between designer and metallurgist is recommended, and descriptions are given of several novel instruments now available to engineers which enable them to develop and test new designs with an accuracy hitherto impossible.

Cast and Forged Steels Compared. C. E. Sims. (Steel, 1945, vol. 116, June 4, pp. 113-116, 152-154; Foundry, 1945, vol. 73, May, pp. 90-93, 192-195). This article is based on a report from the Battelle Memorial Institute on research and the development of testing methods for cast and forged steel specimens. After making comparative studies of the physical properties of the two materials, it was found that there is little to choose between forged and cast steel parts. Limited forging of cast blanks was sometimes effective.

Tentative Recommended Methods for Casting Cast-Iron Test-Bars. (Institute of British Foundrymen, 42nd Annual Meeting, June, 1945, Paper No. 827). In 1944 Sub-Committee T.S.4 was appointed by the Technical Council of the Institute of British Foundrymen to complete the work of the original Cast Iron Sub-Committee on methods of casting test-bars in grey iron as specified in British Standards 321 and 786. Their recommendations are now presented.

Methods of Machining and Threading Test Bars Highly Important. W. C. Blott and W. A. Hambley. (Foundry, 1945, vol. 73, May, pp. 85-86). The effect of imperfect machining in the cutting of threads on specimens of grey cast iron for tensile tests on the test results is discussed.

Careless Pouring of Test Bars Cuts Apparent Strength Markedly. T. E. Barlow. (Foundry, 1945, vol. 73, May, pp. 86-87). The importance of casting iron test specimens at a sufficiently high temperature and of controlling the structure is stressed.

Reproducibility of Methods Needed in Testing and Manufacturing. W. L. Collins. (Foundry, 1945, vol. 73, May, pp. 87, 150). Clamps and grips designed to ensure proper axial loading in the tensile testing of cast iron are described and illustrated.

Casting Inspection. (Machinery, 1945, vol. 66, June 14, pp. 649-651). Equipment for performing hydraulic and air pressure tests on hollow castings and testing by flotation in a liquid of suitable specific gravity, by X-rays, ultra-violet light, and magnetic induction are discussed.

Measurement of Dynamic Stress and Strain in Tensile Test Specimens. R. O. Fehr, E. R. Parker, and D. J. De Micheal. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. A65-A71). The tensile strength, the yield strength, and the breakage energy of test specimens of cold-rolled steel and duralumin were determined while the specimens were fractured by a force applied at high speed in a commercial high-speed impact-testing machine. The dynamic tensile strength, the dynamic yield strength, and the dynamic breakage energy were found to be higher than the static values up to the maximum impact velocities of these tests. Some results of these tests, and descriptions of the technique and analysis used are given.

Influence of Rate of Strain and Temperature on Yield Stresses of Mild Steel. M. J. Manjoine. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. A211-A218). The influence of temperature and the rate of strain on the yield stress of mild steel is described for the range of strain rates from 10^{-6} to 10^3 in./in./sec., an increase of 1 to 1,000,000,000, and for temperatures from 25° to 600° C. The results of these tensile tests are plotted to show more clearly the effects of strain-ageing on the yield stress and the ultimate stress. The comparison of the yield stress at various strain rates permits an analysis of the influence of strain to be made. The conditions necessary for discontinuous yielding are described and compared with testing experience.

Yielding and Fracture of Medium-Carbon Steel under Combined Stress. E. A. Davis. (American Society of Mechanical Engineers: Welding Journal, 1945, vol. 24, May, pp. 283-S-294-S). See p. 64 A.

The Notched Bar Impact Test. J. H. Hollomon. (American Institute of Mining and Metallurgical Engineers: Welding Journal, 1945, vol. 24, Apr., pp. 230-S-241-S). See Journ. I. and S.I., 1944, No. II., p. 86 A.

Relations between the Notched Beam Impact Test and the Static Tension Test. C. W. MacGregor and J. C. Fisher. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. A28-A34). The results of static tension tests of both notched and plain bars are compared with those of notched beam impact tests by using true stress-strain values. For the materials tested, it was found that the effect of the tempering and testing temperatures on the energy absorbed per unit of volume was essentially the same for both tests.

Notch-Toughness Tests of Carbon-Molybdenum Pipe Material. W. F. Kinney, I. A. Rohrig, and H. S. Walker. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. 421-429). As a result of the upward trend in the operating temperatures of power stations special steels have been developed for high-temperature steam pipes. The composition, melting practice, heat-treatment, and their effects on the physical properties and microstructure all have a bearing on the performance of the material. The influence of these factors on notch-toughness is of particular interest, and details are given of an investigation on notch-toughness testing. The influence of the shape of the specimen and the heat-treatment on the uniformity of the test results and on the magnitude of the average notch-toughness values was determined at room temperature and at 925° F. A survey of the literature is also included.

A Critical Review of Various Methods of Residual Stress Measurement. C. S. Barrett. (Proceedings of the Society for Experimental Stress Analysis, 1944, vol. 2, No. 1, pp. 147-156). Methods of measuring residual stresses in rods, tubes, rails, wire, thin-walled cylinders, and plates are reviewed.

Stresscoat and Wire Strain Gage Indications of Residual Stresses. A. V. De Forest and F. B. Stern, jun. (Proceedings of the Society for Experimental Stress Analysis, 1944, vol. 2, No. 1, pp. 161-169). Experiments are described in which the stresses in a welded steel plate during bend and tensile tests were studied by patterns in brittle coatings and by stress-strain diagrams obtained from wire strain gauges. The changes in surface stresses caused by welding were also determined by special Bakelite gauges.

Design and Application of a Magnetic Strain Gage. B. F. Langer. (Proceedings of the Society for Experimental Stress Analysis, 1943, vol. 1, No. 2, pp. 82-89). The magnetic strain gage is a device for measuring small displacements in metal. It can be used as a research tool and for the measurement and control of industrial processes. The principles of its design are discussed and various applications are described.

X-Ray Methods in the Field of Residual Stresses. J. T. Norton. (Proceedings of the Society for Experimental Stress Analysis, 1944, vol. 2, No. 1, pp. 157-160). The X-ray diffraction method of measuring residual stresses in metals is described with notes on the precautions to be taken.

Stress Measurement by X-Ray Diffraction. J. T. Norton and D. Rosenthal. (Proceedings of the Society for Experimental Stress Analysis, 1943, vol. 1, No. 2, pp. 73-76). The theory of two methods of measuring stresses at the surface of a specimen by X-ray diffraction is explained. In one, the sum of the principal stresses is based on perpendicular measurements of the lattice parameters in the stressed and the unstressed states. In the other, a perpendicular and an inclined measurement are made to give a stress in a particular direction.

Applications of the X-Ray Method of Stress Measurement to Problems Involving Residual Stresses in Metals. J. T. Norton and D. Rosenthal. (Proceedings of the Society for Experimental Stress Analysis, 1943, vol. 1, No. 2, pp. 77-81). Some practical applications of the X-ray method of determining residual stresses in steel are described. The theory of the process has already been discussed (*see* preceding abstract).

Measurement of Strain in the Plastic Range. G. A. Brewer. (Proceedings of the Society for Experimental Stress Analysis, 1943, vol. 1, No. 2, pp. 105-115). Examples are given of the measurement of plastic strain and the distribution of the elongation along the gauge length of tensile-test specimens. In some cases aluminium-clad steel specimens on which a grid of 0.01-in. squares was printed by the "photogrid" process were used. An attempt was made to assess the ability of steel sheet to bend without cracking by strain measurements in the plastic range.

Application of the Brittle Lacquer Method in the Stress Analysis of Machine Parts. M. Hetenyi and W. E. Young. (Proceedings of the Society for Experimental Stress Analysis, 1943, vol. 1, No. 2, pp. 116-129). Brittle lacquers have been developed under the trade name of "Stresscoat" which are used for studying the distribution of stresses in metals under load. Examples with illustrations showing the stress distribution in cast gear housings, generator brackets, flapper valves and specimens in torsional tests are described.

Some Problems of Residual Stress Related to Metallurgy. J. Erler. (Proceedings of the Society for Experimental Stress Analysis, 1944, vol. 2, No. 1, pp. 205-213). Experiments are described in which the stress distribution along the surface of cast iron and cast steel rolls was studied. The need for specifying the cooling rate in annealing specifications is emphasized.

Studies in Three-Dimensional Photo-Elasticity. M. M. Frocht. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. A10-A16). The results are reported of a photo-elastic investigation of

the stress concentrations produced around open transverse holes in circular shafts which are subjected to pure bending, the axis of the hole and the bending couples being in one plane with the axis of the shaft. This problem is also of practical interest, as open holes in shafts often form part of the lubricating system of a machine, *e.g.*, the crankshaft of an aircraft engine. A comparison of the stress-concentration factors obtained by the three-dimensional photo-elastic technique is made with the results of fatigue tests and strain measurements on large steel shafts.

Studies in Three-Dimensional Photo-elasticity Torsional Stresses by Oblique Incidence. M. M. Frocht. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. A229-A234). A photo-elastic method is described for the study of stresses in cylindrical shafts due to pure torsion, and the equation governing this case is derived.

An Introductory Study of the Mechanism of Plastic Deformation. J. L. Erickson. (Light Metal Age, 1945, vol. 3, Apr., pp. 12-15). A discussion of the principles of plastic deformation which is of special interest to those in the drawing, extruding, rolling, and forming industries is presented. Although aluminium and magnesium are chiefly dealt with, the basic principles apply generally to all metals.

Shrink-Fit Stresses and Deformations. A. W. Rankin. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. A77-A85). Mathematical expressions are derived for the stresses in a solid cylinder of infinite length caused by the action of an applied radial stress distributed uniformly over a single circumferential ring of finite length on the surface of the cylinder. Test measurements of shaft deformations due to shrinkage pressures are included.

Bursting Tests of Steam-Turbine Disk Wheels. E. L. Robinson. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. 373-380). Bursting tests on model discs of steam-turbine-rotor material show that the average hoop stress at bursting speed for a good alloy steel is likely to exceed its tensile strength. A comparison of the tensile strength with the average hoop stress in a wheel gives a reasonable estimate of the safety factor against actual bursting. Test results on low-carbon and high-alloy steels are included.

Testing Wire Wrapped Steel Pipe. S. R. Beitler. (Iron Age, 1945, vol. 155, May 24, pp. 58-61, 128). The results of tests are reported which were conducted on light-weight, high-pressure, wire-wound steel pipe in order to determine its bursting strength when wound with wire at different pitches, and also to discover whether such pipe could be handled in the field without undue risk of damage. These tests were carried out on 120-ft. lengths of 24-in. dia. steel pipe.

Graphitization Caused by Testing Conditions on Carbon-Molybdenum Tubular Creep-Test Specimens. H. J. Kerr and F. Eberle. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, Graphitization of Steel Piping, pp. 1-4). The results are presented of an examination of tubular specimens of 0.5% molybdenum steel after they had been submitted to creep tests for 9000 hr. at 900° F. and for 14,250 hr. at 1050° F., special attention being given to the degree of graphitization.

Carbide Instability of Carbon-Molybdenum Steel Piping. R. W. Emerson. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, Graphitization of Steel Piping, pp. 5-15). An investigation of the causes of failure of a weld in a steam pipe of molybdenum steel is reported. The failure was due to the precipitation of graphite in the parent metal at the edge of the heat-affected zone. The theory is put forward that using liberal quantities of aluminium to deoxidize the steel adversely affects the stability of the carbides.

A Possible Means of Avoiding Local Graphitization of Steels in Service at Elevated Temperatures. G. V. Smith and R. F. Miller. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, Graphitization of Steel Piping, pp. 17-18). A theory, based on the possibility of different types of carbide existing in the same steel, is put forward to explain the graphitization of molybdenum steel which occurs occasionally in the heat-affected zone of welds in high-temperature steam pipes of this steel. During welding, that portion of the pipe which later graphitized, reached about 1350° F. and caused austenite to form. This austenite, having formed at just above the eutectoid temperature, is rich in carbon and transforms, on subsequent cooling, at a lower temperature than would the austenite of the composition of the pipe as a whole; it may therefore form carbide of the Fe_3C type, not $(\text{Fe},\text{Mo})_3\text{C}$. As the former is not so stable as the latter, graphitization is likely to take place where the former is precipitated.

Report on High-Temperature Pipe Weld Investigation. H. Weisberg. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, Graphitization of Steel Piping, pp. 19-29). A molybdenum-steel steam pipe operating at high temperature having failed owing to graphitization, a study was made of the condition of welds in high-temperature steam pipes at other power stations in the United States. Charts are presented showing the plant conditions, the welding conditions, micrographs of both the weld metal and parent metal, and notes on the distribution of any graphite found. Specimens, some stressed at 7 tons/sq.in. and others unstressed, were held at 1000° F. for 936 hr.; there was considerably more graphite in the stressed specimens.

Progress Report on Graphitization of Steam Lines. S. L. Hoyt and R. D. Williams. (American Society of Mechanical Engineers: Welding Journal, 1945, vol. 24, May, pp. 274-S-282-S). Investigations on the graphitization of carbon-molybdenum steel pipes used for high-temperature steam, which are being undertaken at the Battelle Memorial Institute and at university and industrial laboratories, are reviewed. Plain carbon steels graphitize more easily than molybdenum steels. After exposing molybdenum steels at temperatures up to 1125° F. for 1500 hr., only those which had been deoxidized with a considerable amount of aluminium showed graphitization. Specimens in the as-welded condition were more susceptible to graphitization than those given a stress-relieving treatment.

Improving Fatigue Resistance by Shot-Peening. O. J. Horgor and H. R. Neifert. (Proceedings of the Society for Experimental Stress Analysis, 1944, vol. 2, No. 1, pp. 178-190). An investigation is described which showed that the fatigue strengths of plain and of filleted steel specimens were improved by 19% and 31% respectively by shot-peening before testing.

A Study of Residual Stresses and Size Effect and a Study of the Effect of Repeated Stresses on Residual Stresses Due to Shot Peening of Two Steels. H. F. Moore. (Proceedings of the Society for Experimental Stress Analysis, 1944, vol. 2, No. 1, pp. 170-177). Fatigue tests were made on specimens varying from $\frac{1}{8}$ in. to 2 in. in dia. all machined from one $3\frac{1}{2}$ -in. dia. bar; the bars were heated to 1500° F. in a vacuum and cooled slowly in a vacuum. The fatigue strength of the bars increased with decreasing diameter. Attempts were made to determine whether the residual stresses in strip after shot-peening could be removed by the application of fatigue stresses. In the case of structural steel the residual stresses were relieved to a considerable extent but not in the case of carburized and quenched steels.

Measurement of the Damping of Engineering Materials during Flexural Vibration at Elevated Temperatures. C. Schabtach and R. O. Fehr. (Transactions of the American Society of Mechanical Engineers, 1944,

vol. 66, pp. A86-A92). A method and the equipment for measuring the damping of materials are described.

Wear-Resisting Materials for Lathe Construction. R. W. Dayton, C. H. Lorig, and R. E. Adams. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. 199-204). From tests of all materials generally used for the bearing surfaces of lathes, it was found that the combination of hardened steel against alloy cast iron was far more wear-resistant than any other, and it was also adequately scoring-resistant. A process called "flame refining" was developed for improving the wear-resistance of cast iron. An iron treated by this process and used against hardened steel formed the best combination tested, as it had greatly improved wear- and scoring-resistance.

A wear test simulating lathe service showed that to obtain maximum wear with cast iron against hardened steel, the steel should form the moving surface and the cast iron the bed surface.

Hardness and Wear Resistance. M. Littmann. (Engineering, 1945, vol. 159, June 29, pp. 502-503). The relations between the hardness and wear resistance of metals are discussed with special reference to what is actually measured by the scleroscope, Brinell, and Vickers methods. An attempt is made to determine to which properties the wear-resistance of individual metals corresponds.

Changes in the B-H Curves of Iron on Sending Direct Electrical Current through the Specimen during Magnetisation. H. R. Sarna and O. P. Sharma. (Indian Journal of Physics, 1944, vol. 18, No. 4, pp. 243-248). Using Kreiselsheimer's circuit, the effect of passing a direct current through a specimen of iron during magnetization on the hysteresis loop was studied. The loop contracted, the contraction increasing with the current density. The qualitative nature of the phenomenon is explained.

METALLOGRAPHY AND CONSTITUTION

(Continued from p. 68 A)

The Metallurgical Microscope. E. G. Thurlby. (Australian Institute of Metals, Symposium on Recent Advances in Physical Metallurgy: Australasian Engineer, 1944, Nov. 7, pp. 49-51). A detailed account of the principles of the metallurgical microscope is given.

The Electron Microscope in Physical Metallurgy. G. B. O'Malley. (Australian Institute of Metals, Symposium on Recent Advances in Physical Metallurgy: Australasian Engineer, 1944, Nov. 7, pp. 52-55). The principles of the electron microscope are explained and some of its metallurgical applications discussed. As applied to metals, a resolving power of 30 Å. is reported for thin condensed films examined by transmission. For direct reflection, using the scanning method, the present limit is 500 Å. Using the replica technique, which in the present best form, imposes an ultimate resolution limit of 50 Å., etched metal surfaces may be reproduced with an effective resolution of 150 Å. Instrument magnifications up to 20,000 diameters are possible on metal objects, and enlargement up to 100,000 is feasible for visual interpretation. Extreme care and a high degree of skill are essential in the preparation of specimens and the processing of results in all cases.

A New Microscopy and Its Potentialities. C. S. Barrett. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1865: Metals Technology, 1945, vol. 12, Apr.). A new X-ray micrographic technique is described which is of great potential value in physical

metallurgy. The essential elements are a fine-grained photographic plate placed in contact with or very close to the specimen, and an X-ray tube with a target of low atomic number emitting characteristic radiation. Images formed on the plate by diffraction can be enlarged to 100 or perhaps 250 diameters. These X-ray diffraction micrographs show the places where inhomogeneous strain is concentrated. Combined with goniometer measurements, these micrographs show that local rotation at slip lines is less than 0.1° (in slightly deformed ferrite) and is confined to a layer 3 microns thick or less, whereas rotation at the boundaries of deformation twins in ferrite lies in the 0.5 – 1.0° range. Deformation bands can be recognized in the images of grains, as well as deformation twins, annealing twins, included grains, and distortion from scratches and cutting tools. The cold-worked structure persists throughout the recovery period during annealing, and disappears only when it is devoured by strain-free recrystallized grains. The latter grains are easily seen and distinguished from slightly cold-worked grains. The imperfections of cast grains and clusters of similarly orientated crystals in eutectics and eutectoids can be seen. By measuring the directions of the diffracted rays from individual micro-constituents, the method provides a means of identifying them, and makes micro-analysis possible on individual particles.

Macro Etching and Macrography. F. H. Robinson and J. G. Ritchie. (Australian Institute of Metals, Symposium on Recent Advances in Physical Metallurgy: Australasian Engineer, 1944, Nov. 7, pp. 55–60). Methods of polishing and etching specimens of the more important metals and alloys are described.

Experience with the Electrolytic Polishing of Metallographic Specimens. E. B. Bergsman. (Jernkontorets Annaler, 1945, vol. 129, No. 4, pp. 185–192). (In Swedish). Experience gained in the course of four years' operation of the electrolytic method of polishing specimens in the laboratory of Uddeholms A/B. at Munkfors is discussed. The apparatus, which is based mainly on the recommendations of De Sy Haemers, is described. The method has been found somewhat simpler to use than was indicated in previous papers on the subject.

The Polishing and Etching of Metals. J. McAfee. (Australian Institute of Metals, Symposium on Recent Advances in Physical Metallurgy: Australasian Engineer, 1944, Nov. 7, pp. 60–64). Details are given of the reagents and equipment to use for the polishing and etching of iron and steel, copper, aluminium, lead, zinc, magnesium, cadmium, and some alloys of these metals.

The Electrolytic Polishing and Etching of Metals. R. W. K. Honeycombe. (Australian Institute of Metals, Symposium on Recent Advances in Physical Metallurgy: Australasian Engineer, 1944, No. 7, pp. 64–68). Electrolytic methods of polishing ferrous and non-ferrous metals are described and the advantages and disadvantages of the process are discussed.

Electropolishing of Steel for Microscopic Examination. S. R. Prance. (Steel, 1945, vol. 116, Apr. 23, pp. 106–109). A brief account is given of the technique developed by the General Motors Corporation for the electrolytic polishing of metallographic specimens. The electrolyte consists of 800 c.c. of glacial acetic acid with 200 c.c. of 70% perchloric acid; this is aged for 24 hr. before using. After preparing the specimen with "0" and "00" emery paper, the electrolytic polishing takes $1\frac{1}{2}$ –4 min.

"Lead Printing" Ferrous and Non-Ferrous Metals. W. B. Wragge. (Metallurgia, 1945, vol. 32, May, pp. 3–6). A simple technique for making contact prints to detect lead is described. It not only gives satisfactory prints of lead-bearing steels but is also applicable to non-ferrous metals, providing a means of examining the distribution of the lead.

Solution of the Diffusion Equation Applicable to the Edgewise Growth of Pearlite. W. H. Brandt. (Journal of Applied Physics, 1945, vol. 16, Mar., pp. 139-146). The diffusion equation is transformed into a set of coordinates moving with the pearlite interface and a solution applicable to the problem is obtained in the form of an infinite series of terms. Using the first three terms, the velocity of pearlite growth in the edgewise direction is calculated for a plain carbon eutectoid steel from data most of which are obtained by extrapolation.

Standards for Identifying Complex Twin Relationships in Cubic Crystals. C. G. Dunn. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1796: Metals Technology, 1945, vol. 12, Apr.). As it would be very useful for rapid analyses to discover high-order as well as low-order twin relationships, tables have been worked out for the orientation of successive generations of twins.

Orientation Changes during Recrystallization in Silicon Ferrite. C. G. Dunn. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1797: Metals Technology, 1945, vol. 12, Apr.). A report is presented containing data and analyses for primary nucleation in silicon ferrite following small deformations. The analyses were made with the aid of the standard groups of twins referred to in the preceding abstract. Third-order twin transformations in the silicon ferrite were established.

CORROSION OF IRON AND STEEL

(Continued from pp. 69 A-70 A)

Boiler Embrittlement. C. A. Zapffe. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. 81-117). A historical review of researches on boiler embrittlement is given. All work published in America, England, Germany, France, Sweden, Italy, and Russia—the bibliography comprises 427 papers—is critically evaluated, special attention being given to the rôles of stress, caustic material, chemical attack, ageing, hydrogen, and all other possible factors. These factors are identical with those related to the attack of steel by hydrogen at elevated temperature. The author defines "boiler embrittlement" as an intermediate stage in a naturally occurring hydrogen purification treatment. The conclusions drawn from the review are:

(1) The steam-iron reaction, which can progress more or less continuously at places where a caustic solution has concentrated leads to an almost continuous infiltration of hydrogen into the steel. (2) The hydrogen reacts with the non-metallic inclusions to form gaseous products within the steel. (3) These gases accumulate under pressure within the grain boundaries and at inclusions until their pressure exceeds the cohesive strength of the grains, and the granular structure is stressed to disruption. This condition is recognized as "boiler embrittlement." (4) Disruption of the grains permits the gases to travel until a portion escapes into the atmosphere, constituting the first actual removal of non-metallic inclusions and initiating actual purification. (5) The degassing continues until the reactions are complete and insufficient gas remains to force itself through the structure out to the surface.

Report on Stress Corrosion Cracking of Boiler Plate Steel. J. T. Waber, H. J. McDonald, and B. Longtin. (Welding Journal, 1945, vol. 24, May, pp. 268-S-273-S). An account is given of an investigation at the Illinois Institute of Technology of the cracking of stressed specimens of basic open-hearth and basic-Bessemer low-carbon boiler steels in solutions of

ammonium nitrate, ammonium chloride, and calcium nitrate. The loss of weight was greatest in ammonium nitrate solution and least in calcium nitrate. The effect of different heat-treatments on the crack sensitivity is discussed.

High-Temperature-Steam Corrosion Studies at Detroit. I. A. Rohrig, R. M. van Duzer, jun., and C. H. Fellows. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. 277-288). A report is given of a large-scale investigation to determine the rates of corrosion and the relative corrosion resistances, in an unstressed condition, of 46 ferrous and non-ferrous alloys used in the construction of steam generators, piping, and turbines. Specimens were exposed in a steam atmosphere at 380 lb./sq.in. and at temperatures of 925° and 1100° F. under plant-operating conditions, for periods ranging from 4000 to 16,000 hr. Trends in the corrosion rate were plotted for some of the materials.

The Corrosion of Alloy Steels by High-Temperature Steam. G. A. Hawkins, I. T. Agnew, and H. L. Solberg. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. 291-294). Some tests on the relative resistance to corrosion by steam were made using unstressed specimens of various alloy steels at temperatures between 1000° and 1800° F. Except for the very high chromium-nickel steels all of them showed rapid corrosion at above a critical temperature which increased with the chromium content. Data are given as to the composition of the scale layers formed during tests at 1500-1800° F.

Effect of Combined High Temperature and High Humidity on the Corrosion of Samples of Various Metals. W. L. Mancher and B. W. Jones. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. 624-632). A report is given on how specimens of chromium steel and a number of non-ferrous alloys withstood the hot, humid, corrosive atmosphere at an oil refinery on the Gulf of Mexico.

Corrosion by Phenol at High Temperatures. A. Wachter and N. Stillman. (Electrochemical Society, Apr., 1945, Preprint No. 11). Refining in the petroleum industry sometimes involves the use of phenol at high temperatures so that the corrosion of steel by this liquid is of importance. A simple procedure by which this could be studied is described and some of the results obtained with it are discussed. Small additions of water (0.2% to 0.6%) to anhydrous phenol markedly decrease the corrosion rate of low-carbon steel, although further additions of water increase it. This corrosion-inhibiting action is attributed to the formation of a protective blue-black film found by electron diffraction to be Fe_3O_4 . Increasing the temperature to about 200° C. greatly increases the corrosion of low-carbon steel.

Corrosion of Steels in Marine Atmospheres and in Sea Water. C. P. Larrabee. (Electrochemical Society, Apr., 1945, Preprint No. 12). Data are presented which show that the corrosion of steels in various atmospheres depends upon the amount and type of pollution in the atmosphere and the composition of the steel or alloy. The corrosion of plain and low-alloy steels in sea-water is at the rate of about 22 mg./sq.dm./day. The corrosion of stainless steel is characterized by pitting, but additions of 2-3% of molybdenum will usually prevent serious deep pitting.

The Substitution of Blackplate for Tinsplate in Cans for Fruit and Vegetables. W. B. Adam and D. Dickinson. (Iron and Steel Institute, 1945, this Journal, Section I). A study has been made of the effect of substituting lacquered blackplate ends for tinsplate ends in fruit and vegetable cans. The points noted were the rate of formation of hydrogen in the cans, the rate of dissolution of iron and tin, and the effect of the substitution on the colour and flavour of the contents. The main conclusions reached were as follows:

(1) Cold-reduced plate is superior to hot-rolled plate on blackplate ends covered with a single roller-coating of lacquer. Phosphating does not reduce the rate of internal corrosion and may increase it if the lacquer adheres indifferently to the surface of the plate.

(2) Types of lacquer vary in the protection they afford. Lacquered blackplate ends, with a further dipped coating of lacquer, give results which are comparable with standard lacquered or plain tinplate ends.

(3) The rates of attack of the various fruits and vegetables on blackplate ends differ greatly and are highest for the acid fruits and beetroot.

(4) The substitution of blackplate for tinplate ends does not affect the colour and flavour of vegetables if the lacquer protection is of average efficiency. The situation is much less satisfactory with fruits.

(5) The substitution of blackplate for the bodies of cans as well as the ends is impracticable for general use, but the effect on the storage properties is very similar to that observed in cans with tinplate bodies and blackplate ends.

In these tests the weight of the lacquer film on the phosphated plate was the same as that on the untreated blackplate. Better results were obtained when heavier films were used with phosphated plate.

Corrosion Preventives. J. R. C. Boyer. (Steel, 1945, vol. 116, June 11, pp. 128-132, 176, 178). A survey is given of a wide variety of materials for preventing the deterioration of metal surfaces. Types of coatings, neutralizers and inhibitors, and their functions and applications are discussed. The removable coatings dealt with include: Solvents, greases, oils, water-grease emulsions, plastics, and inhibitors. Some notes on the proper wrapping for dispatch and storage of protected finished products are included.

Specifying Rust Preventives. I. Albin. (Iron Age, 1945, vol. 155, June 7, pp. 52-59). Petroleum-base products for preventing rust are classified in a comprehensive table which is intended to assist in the selection of the product most suitable for protecting a part or a machine under any particular conditions. Their properties are discussed.

ANALYSIS

(Continued from pp. 46 A-49 A)

Modern Analytical Methods. (Coke and Smokeless-Fuel Age, 1945, vol. 7, May, pp. 91-92; June, pp. 110-111, 114). In recent years great progress has been made in the apparatus, methods, and reagents for chemical analyses. Some modern analytical processes are described and their possible application in the coke-oven laboratory is discussed.

Rapid Photometric Determination of Silicon in Low Alloy and Stainless Steels. D. Rozental and H. C. Campbell. (Industrial and Engineering Chemistry, Analytical Edition, 1945, vol. 17, Apr., pp. 222-224). A method for the spectrophotometric determination of silicon in low-alloy and stainless steels is described which is rapid and simple, and uses water as a reference sample. The method is subject to interference from chromium only.

Determination of Iron in the Presence of Cobalt. E. A. Brown. (Industrial and Engineering Chemistry, Analytical Edition, 1945, vol. 17, Apr., pp. 228-230). A colorimetric thiocyanate method is given for the estimation of 0.07 to 0.5 mg. of iron in the presence of variable amounts of cobalt up to 90 mg. A filter-type photometer with two colour filters is used to circumvent the interference of the cobalt ion colour.

A Volumetric Method for the Simultaneous Determination of Iron, Vanadium and Chromium. W. Kriesel. (*Metall und Erz*, 1942, vol. 39, No. 8, pp. 143-144). Details are given of a volumetric method for determining iron, chromium, and vanadium, which can be applied to slags, ores, liquors containing vanadium and to ferro-vanadium.

Application of Colorimetry to the Analysis of Corrosion-Resistant Steels. O. Milner, K. L. Proctor, and S. Weinberg. (*Industrial and Engineering Chemistry, Analytical Edition*, 1945, vol. 17, Mar., pp. 142-145). A colorimetric method, using hydrogen peroxide to remove any molybdenum or vanadium, for determining traces of titanium in corrosion-resistant steel is described.

Some Factors Affecting the Precision in Polarographic Analysis. F. Buckley and J. K. Taylor. (*Electrochemical Society*, Apr., 1945, Preprint No. 17). The factors influencing the variables of the Ilkovic equation are analysed. Tolerances in the control of the experimental conditions are estimated which permit chemical analyses or determinations of diffusion-current constants to be made with a precision of $\pm 2\%$. The presence of peaks in the current waves and the effect of their suppression on the diffusion current are discussed.

A Rapid Method for Determination of Silica in Iron Ore and a Spectrophotometric Method for Phosphorus. C. C. Hawes. (*American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1794: Mining Technology*, 1945, vol. 9, Mar.). A method for determining silica in iron ore is described in which a mixture of 10 parts of sodium carbonate and 2 parts of zinc oxide is mixed intimately with 0.5 g. of the ore and heated for 20 min. No fusion takes place but a grey button is formed. This button, containing all the silicates, is easily dissolved in hydrochloric acid. Perchloric acid is used to dehydrate the silica. After dissolving the button in hydrochloric acid the solution is filtered and the filtrate retained for determining the phosphorus by adding a molybdate reagent to produce the yellow phosphorus colour; the phosphorus is then determined with a spectrophotometer.

Spectrographic Limit of Detection of Phosphorus, Titanium and Zirconium in the Direct Current Arc. D. P. Norman and W. W. A. Johnson. (*Industrial and Engineering Chemistry, Analytical Edition*, 1945, vol. 17, Apr., pp. 233-235). The limits of spectrographic detection for phosphorus, titanium, and zirconium were investigated in a series of National Bureau of Standards samples. The samples were weighed directly into a cored graphite electrode which was used as the cathode of a conventional direct-current arc operated at 15 amp. The limit of detection for phosphorus ranged from 0.05 to 0.80 mg. in nine different standard samples containing from 0.0013% to 0.59% of phosphorus. The limit for titanium ranged from 0.04 to 4 mg. in twelve samples containing from 0.0018% to 0.23% of titanium. The limit for zirconium was from 0.5 to 4 mg. in six samples containing from 0.0037% to 0.19% of zirconium.

Machining Spectrographic Samples. C. L. Waring. (*Metals and Alloys*, 1945, vol. 21, Apr., pp. 1013-1014). The procedure for preparing specimens for spectrographic analysis is briefly described.

How White Motor Company Checks Steel Analyses. (*Steel*, 1945, vol. 116, June 11, pp. 120-122, 158-162). An apparatus is described with which the analysis of steel bars can be rapidly checked against that of a standard bar of known analysis. The instrument is called an "Identometer." The principle employed is that of measuring the thermo-electric e.m.f. generated when a junction between two dissimilar metals is heated. The bar to be tested is placed so that it rests across and in contact with the upper surface of the standard bar; a heating current is applied and leads are also connected to the Identometer which indicates the thermo-electric

e.m.f. on a suitable calibrated dial. If the two bars are of the same analysis no e.m.f. will be generated, but if they are of different composition, the pointer will immediately indicate this.

An Electric Furnace for the Rapid Determination of Carbon and Hydrogen in Coal. C. W. G. Ockelford. (Fuel in Science and Practice, 1945, vol. 24, May-June, pp. 64-65). A detailed description is given of a small electric furnace for the determination of carbon and hydrogen in coal by the Fenton method.

Continuous Determination of Oxygen and Combustibles. J. F. Luhrs. (Iron and Steel Engineer, 1945, vol. 22, May, pp. 45-51). In view of the fact that there is an almost constant relationship between the excess air and the oxygen content of flue gases regardless of the fuel or combination of fuels used, an automatic oxygen recording instrument would be of very great assistance to furnace operators. Such an instrument has been designed and is described in this paper. The sampling equipment and its position in the furnace, as well as some results obtained with it, are discussed.

Problems Concerning the Microchemical Balance. C. L. Wilson. (Metallurgia, 1944, vol. 31, Dec., pp. 101-102). The precautions to be taken when installing a microchemical balance are discussed.

BOOK NOTICE

(Continued from pp. 71 A-74 A)

CHESTERS, J. H. "*Steelplant Refractories.*" Testing, Research, and Development. 8vo, pp. xi + 509. Illustrated. Sheffield, 1944: The United Steel Companies, Ltd. (Price 36s.).

During recent years such strides have been made in the study of refractories in both laboratory and plant, and such marked advances made in the provision of refractories for general and special purposes, that it has become increasingly difficult to keep abreast of all that has been done, even in a particularized field such as steelmaking. The growing realization that refractories are key products has made the metallurgist refractories-conscious, and the publication of this finely conceived book (a preliminary notice of which appeared on p. 24 A) is therefore very timely in putting the present position before all concerned in the production, selection, and use of refractories for the steelplant. Very definite indications are given throughout the book of the important part which collaboration between the maker and user of refractories has played in the advances which have been made. There has been no more consistent advocate of the importance of this collaboration than the late Dr. Thomas Swinden, to whom the book is dedicated, and who wrote the Foreword to it, and it is tragic that he did not live to see its publication, with its vindication of his policy of "constant encouragement and guidance" to efforts which have borne such commendable fruits. It is an especial pleasure to the writer to review this book, as it was under his guidance that the author commenced his study of the technology of refractories. The book is divided into fourteen sections, each section dealing with a particular field; but in general it may be considered as in two parts, one dealing with the general properties of the various types of refractories, and the other with the application of these refractories in various locations in the steelworks. As the records of investigations of special interest are widely scattered throughout the literature of the metallurgical, refractories, and ceramic industries and in various journals of research, the selected bibliography at the end of each section, classified under broad subject headings, is of great value to those who wish to pursue the subject. The first section very properly deals with the subject of testing and the interpretation of test results, and it is timely that attention is directed to the desirability of setting up international standard methods of testing. A useful introduction to the statistical treatment of test data is given, and although little is said directly on the question of sampling, the importance of proper sampling is indirectly emphasized in the selected histograms. A clear statement is given of the applications of microscopical and X-ray examination, and although the latter

has to some extent been used to check the petrological findings, its possibilities are so great that the likelihood is that this procedure will be reversed.

A prominent place is wisely given to the phase-rule treatment of the study of the reactions occurring in the production and usage of refractories. The equilibrium diagram was first applied in the field of silica refractories, but most of the comparatively recent advances in basic refractories, and especially in such composite materials as the chrome-magnesite brick, are directly attributable to fundamental investigations. It is notable that the large proportion of the equilibrium diagrams instanced in the text are the results of American investigations, and whilst investigations in this country have become increasingly active in fundamental work, it is surely desirable that this country should have a laboratory on the same lines, and with the same resources, as the Geophysical Laboratory of Washington, to the work at which we owe so much of our fundamental knowledge. It is not too much to say that the transformation of the manufacture of refractories from an art to a science depends primarily on fundamental study, and it is fortunate that the British Refractories Research Association has this well in the forefront of its developments.

The applications of refractories in the open-hearth furnace have received more attention from investigators than any other part of the steel-making plant, and the logical treatment of the selection and use of the different types of refractories for the various parts of acid and basic open-hearth furnaces is commendable. Besides giving a critical description of present practice, definite indications are given of the lines on which improvements are likely to be effected. Chrome-magnesite bricks are considered from the standpoint of the properties of spinels, their lattice dimensions, and behaviour under equilibrium conditions, and if this type of brick is the answer to the insistent demand for the all-basic furnace, it is clear that the production of durable bricks will depend on the application of these fundamental studies. The developments in the production of dolomite bricks have been of great importance to this country during the war years, and their fields of service are admirably illustrated. Although semi-stable and stabilized dolomite bricks have their limitations, they have their definite fields of applicability in the steelplant; the reference to their promise in the basic cupola is of particular interest.

The casting pit is well surveyed, and the influence of the refractories used on the production of clean steel is discussed with particular reference to the vexed question of the origin of non-metallic inclusions.

The questions of fuel conservation and the thermal efficiency of furnaces are much to the fore to-day, and in the last section of the book effective consideration is given to the properties and application of insulating refractories and the methods of calculating heat flow through furnace walls.

The style and general presentation of the matter in this book are pleasing, and are as refreshing as would be expected from the personality of the author. It is produced in an attractive style, especially well illustrated, and the publishers are to be complimented on the selection of a most readable type. There can be no better summing up of the book than that given in the ASLIB list, "An up-to-date, comprehensive and well-documented account of the choice, testing and application of refractories to steelmaking." It will deservedly find a place on the bookshelf of all who are concerned in any way with the manufacture or use of steelmaking refractories, and, with its clear expression, it can be recommended also as a textbook for students. A word of thanks is offered to The United Steel Companies, Ltd., not only for facilitating the publication of this book but also for making it available at what in these days is such a reasonable price.

W. J. REES.

MINERAL RESOURCES

(Continued from p. 76 A)

The Geological Sequence of the South Wales Coalfield : The "South Crop" and Caerphilly Basin and Its Correlation with the Taff Valley Sequence. L. R. Moore. (Proceedings of the South Wales Institute of Engineers, 1945, vol. 60, No. 3, pp. 142-227).

The Hematite on Black Island, Lake Winnipeg, Manitoba. G. M. Brownell and A. E. Kliske. (Transactions of the Canadian Institute of Mining and Metallurgy, 1945, vol. 48, pp. 284-293). A report is presented on the geology of the hematite deposit which occurs on the southern shore of Black Island, Lake Winnipeg.

Analyses of Tennessee Coals (Including Georgia). (United States Bureau of Mines, 1945, Technical Paper No. 671). A comprehensive report is presented of the geology, production, preparation, analyses and uses of the coals produced in Tennessee and Georgia.

REFRACTORY MATERIALS

(Continued from p. 50 A)

Properties of Refractories. J. A. Kayser. (American Foundrymen's Association : Foundry, 1945, vol. 73, Apr., pp. 113-114, 224-228). American practice in the manufacture of refractory bricks is described and the properties of the various kinds of brick are discussed.

The Behaviour of Chrome Ores and Chrome-Magnesite Bricks in Reducing Atmospheres. T. R. Lynam, T. W. Howie, and J. H. Chesters. (Transactions of the British Ceramic Society, 1945, vol. 44, May, pp. 63-67). The abnormal firing expansion, high porosity and crumbliness of certain chrome-magnesite bricks are found to be due to the use of chrome ores that show abnormal expansion in a reducing atmosphere at a temperature as low as 450° C. With most chrome ores the effect is negligible, but with ores from certain countries it is very marked. Chrome-magnesite bricks made from certain of these ores show the effect if heated for a sufficiently long period in reducing atmospheres or when exposed to iron oxide from the furnace bath. The mechanism of the effect is not clear, but since it is particularly marked in opaque ores high in iron oxide (especially if the latter be present in the free state), it may well be similar to the carbon deposition believed to be responsible for the disruption of blast-furnace bricks.

Service Life of Open-Hearth Silica Brick Roofs. M. A. Fay. (American Institute of Mining and Metallurgy : Steel, 1945, vol. 116, June 25, pp. 114-158). A theory for the fluxing action which erodes the surface of silica bricks in open-hearth furnace roofs is put forward. The eroding medium is the liquid formed by the fluxing of the silica, by constituents in the original brick and by dust and vapours in the furnace atmospheres. It is suggested that the life of the bricks would be considerably improved by eliminating alumina as a brick constituent.

FUEL

(Continued from 77 A-78 A)

Coal Preparation : Second Report of No. 4 Sub-Committee of the Yorkshire Advisory Committee on Mining Research. (Transactions of the Institution of Mining Engineers, 1945, vol. 104, Apr., pp. 297-305). This report covers two aspects of coal cleaning and preparation. The first is the state of efficiency of existing plant and the operation thereof, and the second is the selection of new types of washeries to meet post-war requirements.

The Flow of Air and Gas in Vertical Flue Coke Ovens. G. A. Davis. (Blast Furnace and Steel Plant, 1945, vol. 33, May, pp. 568-578). Methods of calculating the distribution of pressure and flow of air and gas in regenerator flues for heating coke-ovens are discussed with special reference to the design of flues and ports in Wilputte ovens.

Coke from Illinois Coals. F. H. Reed, H. W. Jackman, and P. W. Henline. (Industrial and Engineering Chemistry, Industrial Edition, 1945, vol. 37, June, pp. 560-566). An account is given of work done by the Illinois State Geological Survey on the problem of substituting mid-western coals for a portion of the eastern high-volatile coals which are at present brought a long distance by rail to mid-western coke-ovens. To test the coals under carefully controlled conditions an electrically heated oven taking a 500-lb. charge was designed. A detailed description of this furnace is given.

A Laboratory Method for the Determination of the Suitability of South African Coal and Coal Blends for the Manufacture of Metallurgical Coke. R. F. J. Teichmann. (Journal of the Chemical, Metallurgical and Mining Society of South Africa, 1945, vol. 45, Mar.-Apr., pp. 202-211). A visual examination of the coke produced from small samples of coal or coal blends by the slow-heating method of the Woodall-Duckham Company in a D-shaped oven was found to assist in determining the physical suitability of the coke for metallurgical purposes. A description is given of a laboratory method for determining abrasion indices of small quantities of coke. The results obtained by the visual examination in conjunction with the abrasion indices were compared with the results of examination of the coke obtained by carbonising the same coals in a box inserted in the coke-ovens at the Iscor plant, and satisfactory agreement was obtained.

Some Practical Aspects of the Manufacture of Producer Gas. E. Wood. (Proceedings of the Staffordshire Iron and Steel Institute, 1942, vol. 57, pp. 86-100). The theory of the reactions taking place in gas producers are explained, and the practical application of these theories and other factors in the successful operation of producers are fully discussed.

Determination of Dust in Blast Furnace Gas. D. G. Hisley. (Iron and Steel Engineer, 1945, vol. 22, June, pp. 47-48). A description is given of a simple apparatus for determining the amount of dust in blast-furnace gas. It consists of a glass sampling tube, a 300-c.c. flask containing 25 c.c. of distilled water, a glass tube (1½ in. in dia. × 8 in. long) filled with sugar to act as the filter, a gas meter, and an eductor siphon connected up with rubber tubing. The sugar method was more satisfactory than the standard thimble method.

PRODUCTION OF IRON

(Continued from pp. 78 A-79 A)

Coke Oven and Bast Furnace Operation. J. B. Hill. (Iron and Steel Engineer, 1945, vol. 22, June, pp. 71-74). Major and minor details in the successful operation of blast-furnaces are discussed, and stress is laid on the necessity of having an intelligent, watchful, and active team of men to work the furnace.

The Distribution of Materials in the Blast Furnace.—Part I. H. L. Saunders and R. Wild. (Iron and Steel Institute, 1945, this Journal, Section I). The distribution of materials in the blast-furnace has been studied by the aid of small-scale models, using materials of correspondingly small size. The nature and extent of segregation depend on the character of the materials, *e.g.*, variation in size, shape, density and moisture content, considered in relation to the furnace lines, bell and throat design, &c. Such variables are treated first singly and then in groups, the distribution patterns obtained being followed photographically. The form of the stockline contour, which can be deduced from a knowledge of the trajectories, largely determines the initial distribution which generally persists throughout the furnace shaft. Some examples of burden flow with spherical material are considered. Many illustrations are shown of simple and complex segregations, which are compared according to their origins, together with simple examples of compensation.

Modern Electro-Treatment Processes for the Extraction of Minerals. A. G. Robiette. (Institute of Metals: Metal Treatment, 1945, vol. 12, Summer Issue, pp. 116-127). Some of the electro-thermal processes for the extraction of minerals which could profitably be developed in Scotland, if sufficient cheap hydro-electro power were available, are discussed. These include the manufacture of calcium carbide, ferro-silicon, ferro-chromium and carbon electrodes.

Trial Run is Made at Sponge Iron Plant. W. A. Hauck. (Steel, 1945, vol. 116, June 25, pp. 122-123, 166-170). A report is presented on the construction of a pilot plant designed to produce briquetted sponge iron at the rate of about 100 tons per 24-hr. day. The ore used is a fine magnetite concentrate produced from low-grade magnetite mined in New York State; it is reduced in a Herreshoff roasting furnace, 52 ft. high and 22 ft. in dia. with 12 hearth plates one above the other. The reducing agent is prepared from coke-oven gas and contains about 53% of hydrogen and 28% of methane. A trial with some of the product in an electric furnace was quite satisfactory. Improved briquetting machinery is required.

Presses and Processes for Metal Powder Products. E. V. Crane and A. G. Bureau. (Transactions of the Electrochemical Society, 1944, vol. 85, pp. 63-85). A comprehensive review is presented of the machinery and processes for powder-metallurgy as they exist in America to-day.

Bonding Metal Particles by Heat Alone without Pressure. L. Delisle. (Transactions of the Electrochemical Society, 1944, vol. 85, pp. 135-150). The results are reported of microscopic examination and a few physical tests of specimens made of metal powder by sintering in hydrogen for 3 hr. at various temperatures. Iron, copper and silver particles were investigated. Particle size is a very important factor affecting the bonding between particles. Cold-working the powder appears to lower the temperature at which bonding starts. The addition of a little graphite to electrolytic iron seems to have a similar effect.

Review of Patents on Electrolytic Methods for Making Powdered Metals. J. Rossman. (Transactions of the Electrochemical Society, 1944, vol. 85, pp. 169-172).

FOUNDRY PRACTICE

(Continued from pp. 79 A-82 A)

The Present and Future of Ironfounding. J. G. Pearce. (Bulletin of the British Cast Iron Research Association, 1945, vol. 8, July, pp. 9-12). The development of ironfounding in Great Britain is briefly reviewed and data on the distribution of the total production of iron castings for different industries are presented.

Gray Iron Castings for Power Plant Equipment. P. Dwyer. (Foundry, 1945, vol. 73, May, pp. 108-111, 210-214; June, pp. 97-98, 216-218). An illustrated description is given of the equipment and technique at the foundry of the Elliott Co., Jeannette, Pennsylvania, where a great variety of castings is made, including large castings for steam turbines.

Preliminary Investigation of Metal Pouring by Ciné Radiography. S. L. Fry. (Institute of British Foundrymen: Foundry Trade Journal, 1945, vol. 76, July 12, pp. 213-216; July 19, pp. 239-244). See p. 80 A.

Two Anomalies of Graphitization. L. Crome. (Foundry, 1945, vol. 73, June, pp. 100-101, 246-248). Sufficient ferro-silicon was added to a ladle of white iron to change the fracture to grey, and specimens of the white and the grey iron were malleablised by prolonged heating in boxes packed with slag. The white iron was completely graphitised, whilst the silicon-treated iron had considerable amounts of carbide in the structure. When specimens were withdrawn from a high-temperature treatment and given a low-temperature treatment to decompose the pearlite, those which had had a very short high-temperature treatment graphitised completely except for a trace of carbides at the surface. Additions of up to 0.04% of aluminium to white iron were found to cause some primary graphitisation, and helped to decompose pearlite in the second stage of the malleablising treatment. Additions of more than 0.04%, however, frequently caused the malleabilised iron to retain appreciable amounts of small carbide nodules.

Hydraulically-Operated Tilting Crucible Furnace. (Engineering, 1945, vol. 160, Aug. 3, p. 86). A crucible tilting furnace is described which is notable for the complete absence of the usual girders and counterweights for hand tilting. The tilting mechanism is hydraulic. It is constructed in four sizes for oil, pitch or gas firing. The largest size takes a charge of 650 lb. of brass or copper; it can also be used for melting special cast iron.

Production of Cast Rolls in Australia. E. Felton. (B.H.P. Review, 1945, vol. 22, Mar., pp. 1-4). The manufacture of cast steel and chilled iron rolls at the works of the Broken Hill Proprietary Co., Ltd., Newcastle, New South Wales, is described and illustrated.

An Investigation of the Constitution of Certain Foundry Bonding Clays. R. W. Grimshaw and A. L. Roberts. (Institute of British Foundrymen: Foundry Trade Journal, 1945, vol. 76, July 19, pp. 233-238). Some of the methods available for the identification and estimation of the principal constituent minerals in clays are briefly described. Using them, the constitution of an Irish clay "Colbond" was studied in detail. This was found to contain approximately 40% of a kaolinite-group mineral together with 31% of quartz as the principal impurity. The principal mineral in Colbond, and in other bond and refractory clays, was found to differ from kaolinite, and the evidence suggests that it resembles halloysite, a mineral the plasticity and bond strength of which are probably greater than those of kaolinite and some other members of this group of clay minerals.

Foundry Facing Materials. J. A. Ridderhof. (Foundry, 1945, vol. 73, June, pp. 102, 260-264). The use of mould facing materials is discussed and the following recommendations are made: (1) When seacoal is used its

grain size should be about the same as that of the sand; (2) a mechanical mixer should be used in the preparation; (3) check mould and core washes with a hydrometer; and (4) when drying moulds with a gas flame, care must be exercised to ensure that the binder is not burnt out of the mould coating.

Jobbing in a Cast Iron Foundry. F. C. Stephenson. (Institute of Australian Foundrymen: Australasian Engineer, 1945, vol. 44, Apr. 7, pp. 43-47). A number of examples of large iron castings are described to illustrate the skill of the jobbing moulder. The examples include a 6-ft. dia. mixing pan, a large winding drum, a cylinder cover, and a spur-wheel blank.

Precision Casting of Low Alloy Steels. L. W. Gott. (Iron Age, 1945, vol. 155, June 21, pp. 46-55). Details are given of modifications of the "lost wax" process of precision casting which were developed by the Watervliet Arsenal. These enabled numbers of small intricate parts of alloy steel for small arms to be produced with such accuracy that little or no machining was required.

Gadgets and Methods of Supporting Cores Useful to the Jobbing Moulder. H. Holdsworth. (Institute of British Foundrymen: Foundry Trade Journal, 1945, vol. 76, July 26, pp. 261-262).

Accounts and Costs in a Grey Iron Foundry. C. B. Rowles. (Institute of Australian Foundrymen: Australasian Engineer, Science Sheet, 1945, May 7, pp. 2-6). A system of cost accounting suitable for a grey iron foundry making repetition castings is described.

PRODUCTION OF STEEL

(Continued from pp. 83 A-84 A)

Texas Steel. C. T. Post. (Iron Age, 1945, vol. 155, June 28, pp. 58-66). The position of Texas as a market for iron and steel is reviewed and the war-time conditions leading to the construction of the integrated coke-oven, iron and steel plant at Houston, Texas, are discussed. A description of the plant comprising a battery of 78 coke-ovens, a blast-furnace producing 700 tons/day, three 110-ton open-hearth furnaces and mills rolling bars, plates, sheets and wire, is given.

The Water Supply for an Integrated Iron and Steel Works Situated beside a Natural Water Course. H. F. Sträuber. (Iron and Steel Institute, 1945, Translation Series, No. 231). An English translation is presented of a paper which appeared in Stahl und Eisen, 1944, vol. 64, June 8, pp. 373-377 (see Journ. I. and S.I., 1945, No. I., p. 9 A).

The Manufacture and Properties of Rimming Steel. G. R. Bashforth. (Proceedings of the Staffordshire Iron and Steel Institute, 1942, vol. 57, pp. 36-50). Some of the literature and the author's own experience concerning the manufacture of rimming steel are reviewed. The chief factors in the production of an ingot which neither rises nor sinks appreciably appear to be: (1) Selection of raw materials so as to avoid elements such as silicon, nickel and copper which may affect the solubility of gas; (2) sufficient carbon in the melt to ensure a good vigorous boil which controls oxidation and the occluded gas content; (3) proper slag formation to ensure that the slag gives adequate protection of the metal against gas absorption and yet sufficiently free to allow the escape of gas; (4) the application of the Brinell density quotient, the value of which must be determined for each plant and practice; (5) the accurate control of temperature throughout the working of the charge; and (6) the standardisation of casting-pit

practice, with special reference to the method, temperature and rate of teeming, mould design, the cleanliness and temperature of the moulds, and the freedom from moisture in the launder, chute, ladle lining and runner bricks.

Melt Control, Its Evolution and the Effect of a Current Control Method on Basic Open Hearth Operations. A. M. Kroner. (American Institute of Mining and Metallurgical Engineers: Blast Furnace and Steel Plant, 1945, vol. 33, May, pp. 561-567). Changes in the control procedures for 145-ton open-hearth furnaces which were introduced by the Inland Steel Co. to provide for the changes in steelmaking practice from high scrap charges to high hot-metal charges are described. The new procedure provides a base factor for the final carbon content desired, with supplementary correction factors for the amounts of scrap, limestone, cold iron, hot metal, and silicon in the hot metal. An example of the application of the method is cited; experience over a period has shown that since it was introduced the average time from charging to tapping, the fuel consumption, and the ore additions have been reduced and the production per hour has increased.

Steel for Sheets. H. J. Merchant. (Proceedings of the Staffordshire Iron and Steel Institute, 1942, vol. 57, pp. 52-79). A comprehensive description is given of the properties required in sheets for motor-car bodies, shallow pressing, metal coating, enamelling, welding and structural purposes. Details are given of the melting and rolling practice, and the relative merits of running and killed steel are discussed. The causes of defects in sheets are dealt with.

Some Notes on the Basic Arc Process. G. R. Bashforth. (Proceedings of the Staffordshire Iron and Steel Institute, 1941, vol. 56, pp. 1-16). A comprehensive description is given of the theory and practice of steelmaking in the basic-lined electric furnace.

Basic Electric Steel Melting. J. G. McMaster. (Australian Institute of Metals: Australasian Engineer, 1945, vol. 44, May 7, pp. 39-47). A detailed description is given of the process of making steel in the Héroult basic-lined electric furnace under Australian conditions.

Unusual Applications of Motor Control. P. B. Harwood. (Iron and Steel Engineer, 1945, vol. 22, June, pp. 50-57). Some problems in the design of limit switches and motor-control circuits are discussed. These include: (1) The interlocking of the bridges of three cranes working on one track to prevent any two cranes approaching each other too closely; (2) the control of motors operating furnace doors; and (3) interlocking the motions of an ingot manipulator.

REHEATING FURNACES

World's Largest Rotary-Hearth Furnace Heats Billets for Piercing Mill. J. H. Loux. (Industrial Heating, 1945, vol. 12, May, pp. 791-800, 861). An illustrated description is given of a very large rotary-hearth furnace, burning either gas or oil, designed to heat 40 tons of steel billets per hr. The outside and inside diameters of the hearth ring are 67 ft. and 36 ft. respectively, and it will take billets up to 10 in. in dia. \times 14 ft. long.

Silicon Carbide Roller Hearths for High-Temperature Industrial Furnaces. M. L. Snodgrass. (Industrial Heating, 1945, vol. 12, May, pp. 834-836). Composite rollers have been designed which considerably extend the service life of the rollers carrying the hearths of rotary furnaces. They consist of a tube of silicon carbide supported on a hollow steel shaft.

Some Aspects of Heating Steel for Forging. F. E. Stokeld. (Drop Forger, 1945, vol. 25, May, pp. 11-18). The methods of heating forgings to obtain products of good quality with a minimum of fuel consumption are

discussed. When a furnace has two chambers, it is important that the preheating chamber is larger than the final heating chamber, because final heating is a rapid process, and an adequate supply of forgings is required from the former to the latter chamber. The installation of recuperators to heat the air for the combustion of oil fuel to 320° C. can effect a saving of about 18% in the fuel consumption. This should receive more consideration than has been the case in the past.

High-Speed Heating with Gas. (Steel, 1945, vol. 116, Jan. 22, pp. 86-90, 129, 130). Several industrial applications of gas heating by radiation are described. For repetition work panels of refractory material are constructed so as to follow the contour of the work to be heated; recessed into the panels are a number of cup-shaped ceramic burners to which premixed gas and air are fed. A very high rate of heating is possible. This system is used for reheating small billets of steel and non-ferrous metals, for annealing stainless steel and for "flowing" tin coatings on steel sheet.

FORGING, STAMPING, AND DRAWING

(Continued from pp 85 A-86 A)

Forging and Heat Treating Engine Sections at the Transue & Williams Plant. (Industrial Heating, 1945, vol. 12, May, pp. 742-758). An illustrated description is given of the forging and heat-treatment plant at the works of the Transue and Williams Steel Forging Corporation of Alliance, Ohio, where 3-cwt. billets are forged into crankcase sections for 14-cylinder aero-engines.

Metallurgical Aspects of Alloy Steel Aircraft Engine Forgings. A. J. Pepin and A. L. Rustay. (Metal Progress, 1945, vol. 47, June, pp. 1107-1114). A description is given of the various control tests which are applied at different stages in the manufacture of aircraft engine forgings of nickel-chromium-molybdenum steels.

Nosing 8-In. H.E. Shells on a 4500-lb. Steam Hammer. A. B. Salkeld. (Industrial Heating, 1945, vol. 12, May, pp. 780-786). The piercing of billets to make 8-in. shells has already been described (*see* p. 55 A). In the present paper details are given of the nosing operation on the rough-machined pierced billet.

Forging Shells by the Pierce and Draw Method. (Iron Age, 1944, vol. 154, Sept. 7, p. 67). The method of piercing and drawing shells of large diameter employed at the Blairsville plant of the Porter-Blairsville Company is described and illustrated.

Forging Die Design. J. Mueller. (Steel Processing, 1945, vol. 31, May, pp. 299-301). The design of dies for forging steel hooks is discussed.

Practical Problems of Light Presswork Production. J. A. Grainger. Sheet Metal Industries, 1945, vol. 21, Feb., pp. 265-272; Mar., pp. 636-640; May, pp. 819-820; June, pp. 1003-1008, 1010; vol. 22, July, pp. 1187-1192, 1194). The importance of correct die clearances, setting stops, safety stops, setting tools, and factors affecting the selection of presses are discussed.

Early Wire History. J. F. Luckman. (Wire Industry, 1945, vol. 12, July, pp. 355-356). A review of the early history of wire-making is presented.

Patenting. (Wire Industry, 1945, vol. 12, July, p. 358). The advantages and disadvantages of heating wire for patenting in gas-fired and in electric furnaces are discussed and compared with the merits of direct resistance heating.

ROLLING-MILL PRACTICE

(Continued from pp. 86 A-87 A)

The Rolling of Metals. Theory and Experiment. L. R. Underwood. (Sheet Metal Industries, 1945, vol. 21, Feb., pp. 245-254; Mar., pp. 429-436; Apr., pp. 613-619, 630; May, pp. 806-809; June, pp. 983-991; vol. 22, July, pp. 1167-1176, 1184). An attempt is made to give a connected account of the interaction of such factors as roll diameter, thickness and width of material, nature of material, draught, friction between the rolls and material, speed, front and back tension and rolling temperature in the rolling of metals. The chief experimental and theoretical work on this subject is examined with a view to forming an opinion as to how far present knowledge can be usefully employed in the solution of everyday rolling problems and as to the direction in which further research work should proceed.

The Measurement and Recording of Roll Pressures. N. de Ball. (Iron and Steel Institute, 1945, Translation Series, No. 237). An English translation is presented of a paper which appeared in *Stahl und Eisen*, 1944, vol. 64, Nov. 9, pp. 716-720 (*see* Journ. I. and S. I., 1945, No. I., p. 103 A).

Lubrication of Metal Surfaces by Fatty Acids. F. F. Bowden, J. N. Gregory and D. Tabor. (Nature, 1945, vol. 156, July 28, pp. 97-101). Some results of recent research on lubrication are reviewed. The longest-chain fatty acids do not lubricate unreactive surfaces at temperatures above about 90° C. The softening points of metallic soaps, however, are usually very much higher than the melting points of the pure acids. For this reason fatty acids are much more effective as boundary lubricants at heavy loads and high temperatures if they are used in the form of metallic soaps; this may be achieved by applying them to metal surfaces with which they react.

West Coast Steel Mill. G. Eldridge Stedman. (Steel, 1945, vol. 117, July 2, pp. 108-110, 158). An illustrated description is given of a merchant bar mill at Torrance, California, where bars, flats and sections are rolled from ingots 13 in. in dia.

The Krause Mill Reduction Line. P. M. Mueller. (Iron and Steel Engineer, 1945, vol. 22, June, pp. 37-45). The principles of the Krause cold-reducing mill have already been explained (*see* Journ. I. and S. I., 1945, No. I., p. 104 A). In the present paper experience obtained with two existing mills rolling brass and copper with very heavy reductions per pass are described. The application of the same principle to the rolling of steel is discussed.

Intermittent-Acting Mills for Rolling Strip. J. D. Keller. (Steel, 1945, vol. 116, June 18, pp. 108-109, 120-126; June 25, pp. 135-139, 173, 174). Rolling mills in which the rolls are not continuously in contact with the work are described. These include the Krause, Evans and Kessler types of mills. The first of these has already been described (*see* preceding abstract). In the Evans mill a series of small-diameter migratory rolls travel through the gap between a large-diameter roll and a fixed semi-cylindrical cross-member or anvil which "backs up" the small rolls. The strip passes round the single large roll through which the torque for rolling is transmitted and is rolled between it and the small migratory rolls. The reduction is affected by the contour of the inner surface of the cross-member, which is such that the gap between it and the large roll is narrower at the exit end than at the entry end. In the Kessler mill the strip also passes round a

large roll and is reduced by the action of small rolls, but in this case the large roll is idle and the strip is pulled through the machine by a tension coiler.

PYROMETRY

High Temperature Measurements of Liquid Steels Using the Quick-Immersion Thermocouple Technique. R. W. S. Freeman. (Canadian Metals and Metallurgical Industries, 1944, vol. 7, Dec., pp. 23-25). A description is given of a modification of the Schofield-Grace quick-immersion thermocouple equipment which was developed for measuring the temperature of liquid 14% manganese steel in an electric arc furnace.

New Device Measures Temperature of Molten Steel. (Steel, 1945, vol. 116, Feb. 26, p. 100). A brief description is given of a quick-immersion thermocouple for taking the temperature of molten steel. It consists of a platinum/platinum-rhodium couple in a fused silica tube mounted in a block of graphite which is fixed to a 12-ft. insulated tube containing the wires connecting it to an electronic recorder.

Thermo-Electric Pyrometers. R. A. Dunkley. (Institute of Instrument Technology: Australasian Engineer, 1945, vol. 44, Mar. 7, pp. 39-41). The principles of thermo-electric pyrometers are explained with an outline of the various types of thermocouples in use for metallurgical purposes.

HEAT-TREATMENT

(Continued from pp. 87 A-88 A)

Heat Treatment of Steel as Related to Design, Materials and Processing. T. F. O'Brien. (Metals and Alloys, 1945, vol. 21, May, pp. 1335-1350). The design of parts, the material to be used and the heat-treatment procedures are discussed in a manner which demonstrates the necessity for the designer, the materials engineer, the machinist, and the heat-treater working in close co-operation.

Metallurgy of SAE 52100 Ball Bearing Steel. R. J. Hafsten. (Iron Age, 1945, vol. 156, July 5, pp. 54-59). Particulars are given of the development of the correct heat-treatment for steel S.A.E. 52100 for ball and roller bearings. This is a 1% carbon steel containing 1-1.5% of chromium and about 0.15% of nickel.

Heat-Treatment of Uncooled Steel and Rationalisation of the Annealing of Cooled Steel at the Zaporozhstal Works. I. P. Lipilin. (Iron and Steel Institute, 1945, Translation Series, No. 230). An English translation is presented of a paper which appeared in *Katshestvennaia Stal*, 1937, No. 10, pp. 5-22 (see Journ. I. and S.I., 1939, No. I., p. 25 A).

Measurement of Case Depths by Martensite Formation. E. S. Rowland and S. R. Lyle. (Metal Progress, 1945, vol. 47, May, pp. 907-912). A method, developed by the Timken Roller Bearing Company, for accurately determining case depth is described. This method makes use of the sharply defined line observed on etched microsections between the higher carbon layer which did not transform into martensite at the quenching-bath temperature and the lower carbon material which did.

Maximum Carbon in Carburized Cases. S. Breitbart. (Metal Progress, 1945, vol. 47, June, pp. 1121-1127). The theory is put forward that the maximum content of carbon obtained at the surface of a carburised case depends on the microstructure of the steel during the process of carburisation. Experiments supplying evidence in support of this are described.

Pairs of rectangular specimens of low-alloy steels, ground and polished on all faces, were immersed in molten cyanide baths; each pair was squeezed together so that no salt could penetrate between the surfaces in contact. After $1\frac{1}{2}$ hr. the pieces were separated and left in the bath for another 7 hr. They were then simultaneously quenched in oil. Micrographs of cross-sections were made and compared. These experiments were repeated in salts of different concentrations at different temperatures and in one case in a gaseous carburising medium. In all the experiments the outer surfaces of the pairs of specimens exhibited coarse carbides in the structure, whilst the inner surfaces (which had, in effect, been given a preliminary austenitising treatment for $1\frac{1}{2}$ hr.) had a fine structure with no coarse carbides. Thus, an excessive carbon content is obtained in the case when the steel contains "free" carbides or carbide nuclei during carburisation, whereas the carbon content is in accordance with the iron-carbon diagram for the particular steel when it consists of homogeneous austenite during carburisation.

Case-Hardening Anomalies. C. A. E. Wilkins. (Metal Treatment, 1945, vol. 12, Summer Issue, pp. 95-103). It is suggested that a standard specification for the surface hardness of case-hardened parts is required and a draft of a specification which includes all the common carburising steels is submitted. Tests on case-hardened steels have shown that low-temperature tempering reduces the surface hardness but increases the toughness of the case. Case-hardening mild steel is more susceptible to tempering than alloy steels. The addition of molybdenum to case-hardening steels causes the hardness of the case to be retained at a much higher temperature than is the case with steels without molybdenum.

The Selection and Heat Treatment of Tool Steels for Post-War Production. C. W. S. Glen. (Australian Institute of Metals: Australasian Engineer, Science Sheet, 1945, Apr. 7, pp. 25-28). Recommendations are made on the correct heat-treatment for different classes of die steels, in particular for a 2%-carbon 12-14%-chromium steel.

Fundamental Principles and Applications of Induction Heating. (Sheet Metal Industries, 1945, vol. 21, June, pp. 1037-1046, 1052). Conclusion of a series of articles (see p. 39 A). The application of induction heating for expanding ring gears on to flywheels and making other shrink fits, for stress-relieving welded joints, and for bending bars and pipes is described.

Heating Metals and Non-Metallic Materials by Electronics. (Machinery, 1945, vol. 67, Aug. 9, pp. 141-147). Four types of induction-heating equipment and some of their applications are described. These comprise: (1) Low-voltage heavy-current equipment at the supply frequency of 50 or 60 cycles per sec.; (2) motor-generator sets producing frequencies of 1000-12,000 cycles; (3) spark-gap oscillators producing frequencies ranging up to 300,000 cycles; and (4) vacuum-tube oscillators with frequencies in the 100,000-5,000,000 cycle range.

Motor Generator and Electronic Units. J. P. Jordan. (Metals and Alloys, 1945, vol. 19, May, pp. 1153-1154). Two types of induction-heating equipment, namely, motor-generator sets with low-frequency spark-gap units and electronic heaters, are compared with notes on the applications for which each type is most suitable.

Spark-Gap Converters. F. T. Chesnut. (Metals and Alloys, 1945, vol. 19, May, pp. 1155-1156). Spark-gap converters with high-frequency motor-generator sets as the source of power are economical for induction-heating small parts up to $1\frac{1}{2}$ in. in dia., for melting on a small scale in the laboratory and, generally speaking, for work requiring frequencies between 12,000 cycles/sec. and the higher radio frequencies supplied by tube converters. Particular applications in the 15,000-60,000 cycles/sec. range are discussed.

Induction Heating Equipment—The Field as a Whole. (Metals and Alloys, 1945, vol. 19, May, pp. 1150-1152). Some war-time applications of induction heating are briefly reviewed and a table showing types of equipment, names of manufacturers, and typical applications is presented.

Electronic Drives on Winding Reels for Metal Strip. J. H. Hopper. (Steel, 1945, vol. 116, May 28, pp. 132-135). A description is given of an electronic control device for the exact regulation of a 2-h.p. winding reel drive which pulls steel strip through a continuous annealing plant. The speed can be varied in the range of 3-12 ft./min.

Salt Baths in the Wire Industry. A. R. Stargardter. (Wire and Wire Industry, 1945, vol. 20, June, pp. 415-419, 448-450). Descriptions are given of three salt-bath annealing plants for steel wire all of which are heated by immersed electrodes. Data on the annealing costs per ton of wire are presented.

Gas Furnaces for Interrupted Quenching. A. H. Koch. (Metal Progress, 1945, vol. 47, May, pp. 921-925). The operations of austempering, isothermal quenching and martempering are explained and gas-fired furnaces for heating salt baths for intermediate quenching are described and illustrated.

Improved Quenching. C. G. Purnell and H. M. Pfahl. (Steel, 1945, vol. 117, July 2, pp. 88-91, 127). Methods of ensuring uniformity in the heat-treatment of small parts are described. These include the controlled agitation of the cooling oil with propellers, accurate timing of the quench, and tempering as soon as possible after quenching.

Progressive Heating, Quenching Eliminates Brittleness and Warpage of Small Parts. A. R. Hotchkiss. (Steel, 1945, vol. 117, July 9, pp. 104, 162). A description is given of a heat-treatment apparatus for steel washers. A small sloping conveyor projecting into the quenching tank is driven by a variable-speed motor. This conveyor has an induction-heating coil through which the washers passed before dropping into the water for quenching.

Methods for the Quenching of Steel. M. H. Mawhinney. (Industrial Heating, 1945, vol. 12, May, pp. 760-770). Conveyors and tank equipment for quenching parts of tractors and other machinery on mass-production lines are described and illustrated.

Quenching Oils. B. B. Wescott and L. W. Vollmer. (Metal Progress, 1945, vol. 47, May, pp. 935-936). Criticisms are made of certain forms of apparatus for determining the cooling rates of steel bars in different oils, and cooling curves for specimens of 18/8 stainless steel are presented and discussed.

What Quenching Oil to Use. W. G. Forbes. (Iron Age, 1944, vol. 154, Aug. 3, pp. 50-51, 136). The relative merits of different oils and oil mixtures for quenching steel are discussed, and reasons are given for the author's preference for a straight mineral oil with a specific gravity reading of 28 or above (hydrometer scale of the American Petroleum Institute).

What Quenching Oil Not to Use. G. W. Pressell. (Iron Age, 1944, vol. 154, Nov. 9, pp. 62-65). The quenching properties of straight mineral oil and of compounded oils are discussed. The author recommends the addition of an oxidation inhibitor.

WELDING AND CUTTING

(Continued from pp. 89 A-90 A)

Application and Development of Modern Heavy-Coated Arc-Welding Electrodes. D. C. Smith and W. G. Rinehart. (Welding Journal, 1945, vol. 24, June, pp. 541-548). The requirements of electrode coatings are discussed, and detailed information is given on the properties and characteristics of welds made with three types of American electrodes. The first type produces a high-quality weld in all positions with deep penetration. The second type has less penetration and can be used to bridge wide openings. The third type is for horizontal welding; by using a high current with a very short arc and travelling at a high speed, a deep penetration is obtained with economy in electrode consumption. The way in which the coating ingredients contribute to these properties is explained.

Applications of Various Resistance Welding Techniques. F. R. Woodward. (Steel Processing, 1945, vol. 31, May, pp. 305-309, 316-318). A number of resistance welding machines for spot, seam and flash welding are described and illustrated.

Some Suggestions on the Fabrication of Stainless Steel. P. F. Voigt. (Steel Processing, 1945, vol. 31, Apr., pp. 217-221, 237; May, pp. 294-298). Recommendations are made on procedures for welding, soldering, riveting, machining, grinding, and polishing ferritic, austenitic and martensitic stainless steels.

Arc Welding of Rail Steel. C. B. Haynes, W. H. Graft, and R. G. Spencer. (Metal Progress, 1945, vol. 47, May, pp. 912-915). Tests are described which were undertaken at the instance of the Rail Steel Bar Association to develop the best technique for welding bars and sections rerolled from manganese steel rails.

Welding Requirements for Various Stainless Steels. W. J. Conley. (Machinist, 1945, vol. 89, June 30, pp. 402-405). Welding techniques for high-alloy chromium and nickel-chromium steels are described.

Stress Relief of Weldments for Machining Stability. J. R. Stitt. (Welding Journal, 1945, vol. 24, June, pp. 331-S-349-S). An investigation is reported the purpose of which was to determine the effect of stress-relieving treatments at maximum temperatures of 900°, 1000°, 1100°, 1200°, 1300° and 1400° F. upon the distortion during subsequent machining of welded structures made of nickel-chromium-molybdenum steel and of three chromium-molybdenum steels. A total of 1800 deflection determinations and 12,500 strain-gauge readings were made. Welding deflection curves were constructed from these data which enable the correct stress-relieving temperatures to be selected to ensure that after each machining operation the structure will remain within the required tolerances.

Electric Furnace Brazing Being Widely Extended. H. M. Webber. (Iron Age, 1944, vol. 154, Nov. 16, pp. 48-52; Nov. 23, pp. 52-56). The brazing together of steel parts in an electric furnace is described and illustrated with examples of light steel-sheet metal components for ordnance and aircraft.

Basic Definitions of Welding Technology. C. H. Jennings. (Welding Journal, 1945, vol. 24, June, pp. 549-553). Definitions and descriptions are given of the forging, gas, thermit, electric-arc and resistance methods of welding.

Removing Risers and Padding by Machine Flame Cutting. R. J. Wolf and J. H. McKlveen. (Foundry, 1945, vol. 73, June, pp. 92-94, 234-236). Illustrated descriptions are given of the application of an oxy-acetylene cutting machine for cutting the risers off large steel castings.

MACHINING

(Continued from pp. 41 A-42 A)

Future of Bessemer Steel for Automatic Screw Machine Products. J. D. Armour. (American Society for Metals; Iron Age, 1945, vol. 155, Mar. 22, pp. 64-65). It is shown that Bessemer steel has excellent machining properties. Several applications of the steel for machined parts are mentioned and further research to widen the field of application is called for.

Increased Efficiency by Increasing the Cutting Capacity. H. Stevens. (Iron and Steel Institute, 1945, Translation Series, No. 223). An English translation is presented of a paper which appeared in *Stahl und Eisen*, 1944, vol. 64, Aug. 31, pp. 564-571 (*see* Journ. I. and S.I., 1945, No. I., p. 54 A).

Machinability of Plain-Carbon, Alloy, and Austenitic (Non-magnetic) Steels and Its Relation to Yield-Stress Ratios When Tensile Strengths are Similar. E. J. Janitzky. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. 649-652). A method of obtaining an index of machinability for the rough-turning of certain steels from the yield-stress/tensile-stress ratio is described, and an equation for the relation between the Taylor speed (the maximum cutting speed at which a standard tool will last for a given period) and the yield-stress ratio is derived.

The "Topograph" Surface-Finish Measuring Instrument. (Engineering, 1945, vol. 159, June 1, pp. 427-428). A detailed description is given of an instrument for evaluating surface finish. It operates on a simple pneumatic principle, and it gives a pen record of an enlarged profile of the surface irregularities along a selected straight line. Irregularities of the order of 2 micro-inches are readily detected.

Basic Mechanics of the Metal-Cutting Process. M. E. Merchant. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. A168-A175). The author presents a mathematical analysis of the geometry and mechanics of the process of cutting metals with lathe tools. This analysis helps to explain the cutting operation by considering such quantities as strain, rate of shear, friction between chip and tool, shear strength of the metal, and work done in shearing the metal and in overcoming friction. Equations are developed which permit the above quantities to be calculated from readily observable values. The theoretical findings are particularly applicable and significant for high-speed machining operations with sintered-carbide tools.

Trouble Shooting Problems in Steel Machining. J. H. Greenberg. (Metal Progress, 1945, vol. 47, June, pp. 1115-1119). A procedure for ascertaining the cause of machining troubles and applying remedies is outlined. The scheme is divided into five parts so that the trouble can be traced to one of the following: The cutting tools, the work, the speed and feed, the cooling agent, or the machine.

CLEANING AND PICKLING OF METALS

(Continued from pp. 61 A-62 A)

Rate of Saponification in Metal Cleaning. R. Twynning and E. M. Baker. (Proceedings of the American Electroplaters' Society, 1943, pp. 105-108). Experiments to determine the rates at which greases and fatty acids can be saponified in hot alkaline solutions are described. The

materials tested were: Hydrogenated stearin pitch, beef tallow, No. 51 hydrofol acid, No. 42 hydrofol glyceride, and stearic acid.

The Effect of Various Anions in Metal Cleaners. E. C. Rinker. (Proceedings of the American Electroplaters' Society, 1943, pp. 109-112). Comparisons are made of the times taken to remove different oils from the surface of steel by means of different alkaline cleaning solutions.

The Operation of Modern Degreasers. J. W. Dammers. (Proceedings of the American Electroplaters' Society, 1943, pp. 113-116). The design and operation of modern solvent degreasing equipment are discussed.

Electropolishing of Stainless Steels. (Iron Age, 1945, vol. 156, July 12, pp. 64-64B, 130). A brief description is given of an electrolytic polishing process for stainless steel which was developed by the Rustless Iron and Steel Corporation. The electrolyte used is a mixture of citric acid, sulphuric acid and water.

Cleaning Forgings for Magnaflex Inspection. E. H. Johnston. (Steel, 1945, vol. 116, May 21, p. 111). A cleaning process is described which not only removes scale but also leaves a clean, bright surface on which Magnaflex powders will stand clearly in relief.

Works Practice in the Pickling of Steel. E. Marks. (Sheet Metal Industries, 1945, vol. 22, July, pp. 1179-1183). Problems encountered in the pickling of steel prior to vitreous enamelling are discussed. When either nickel or copper is present in amounts exceeding 0.15% a "sludge pattern" is liable to form on the surface of the article leaving the pickling bath. A new pickling solution is required which will dissolve all the normal impurities in steel. It is recommended that a standard scale for the efficiency of inhibitors should be established.

Treatment of Spent Pickling Liquors with Limestone and Lime. R. D. Hoak, C. J. Lewis and W. W. Hodge. (Industrial and Engineering Chemistry, Industrial Edition, 1945, vol. 37, June, pp. 553-559). Although a quick-lime slurry is commonly used to neutralise spent pickling liquor, the cost of the treatment can be reduced in many cases by employing a combination of limestone and lime. The actual saving depends largely on the cost of pulverised limestone. There is a critical particle size, between 200 and 325 mesh and differing for different limestones, for the optimum reaction with pickling liquor. When more than about 2% of magnesium carbonate is present in the limestone the rate of reaction with the liquor decreases with increasing amounts of this constituent. The commercial operation of the limestone-lime treatment is described.

COATING OF METALS

(Continued from pp. 62 A-63 A)

The Relation of Defects in Electroplate to the Gas Content of the Basis Metal. C. A. Zapffe and C. L. Faust. (Proceedings of the American Electroplaters' Society, 1944, pp. 93-108). Reasons are given for refuting the theory that when brittleness develops in electrodeposited coatings on iron and steel this is due to the formation of hydrides. There are two possible sources from which hydrogen may enter the plating; these are the electrolyte and the base metal. In the former case the plating ages fairly quickly, even at ordinary temperatures, and the plating becomes ductile as the hydrogen escapes. In the latter case the base metal ages slowly, and the hydrogen diffuses from it into the plating, which becomes brittle upon standing for some time. Experiments illustrating delayed embrittlement are described, and anomalies, such as the formation of more blisters on one side of a specimen than on the other, are discussed.

Chromising Processes. D. W. Rudorff. (Metallurgia, 1945, vol. 32, June, pp. 59-62). A survey is made of recent Russian and German literature on methods of diffusing chromium into the surface of iron and steel parts.

Porous Chrome. H. Van der Horst. (Proceedings of the American Electroplaters' Society, 1943, pp. 56-61). The Van der Horst process of preparing porous chromium coatings on Diesel engine cylinders is described.

Porous Chromium Plating—Principles, Procedures and Operating Practices. T. G. Coyle. (Proceedings of the American Electroplaters' Society, 1944, pp. 20-75). A detailed description is given of the cleaning, plating, etching, finishing and inspection procedures as developed by United Chromium, Incorporated, for the porous chromium plating of aircraft-engine and Diesel-engine cylinders, cylinder liners and piston rings. Over fifty illustrations of the equipment and methods are presented.

The Hard Chrome Plating of Cutting Tools. A. F. Fletcher. (Proceedings of the American Electroplaters' Society, 1943, pp. 82-83). Numerous examples are cited of the increase in the life of cutting tools which was obtained by chromium-plating them.

Hard Chromium Plating. D. A. Cotton. (Proceedings of the American Electroplaters' Society, 1944, pp. 119-136). Three classes of chromium plating are discussed, and numerous examples of their application are described and illustrated. These classes are: (1) Plating on tools and gauges to secure longer life and better finish; (2) plating to increase the life of cutting tools; and (3) plating to build up metal on worn shafts and the like.

Hard Chrome Problems. A. Logozzo. (Proceedings of the American Electroplaters' Society, 1944, pp. 149-155). Procedures for chromium plating are described and the design of plating racks is discussed.

Porous Chromium in Engine Cylinders. Russell Pyles. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. 205-213). Among the properties of porous chromium coatings which contribute to its low rate of wear in engine cylinders are the following: (1) The hardness, which is maintained throughout the case even at high temperatures; (2) the high thermal conductivity which helps to conduct heat away from the cylinder; (3) low coefficient of friction and small affinity for other metals; and (4) high corrosion resistance. These properties are discussed, and the plating, finishing and inspection procedures are described.

Metal Finishing. H. Silman. (Sheet Metal Industries, 1945, vol. 21, Mar., pp. 467-475, 496; Apr., pp. 675-681; May, pp. 859-865; June, pp. 1031-1036). Continuation of a series of articles (*see* Journ. I. and S.I., 1945, No. I., p. 130 A). Modern equipment and technique for the electroplating of chromium, cadmium, lead and zinc are described.

Stress in Electrodeposition of Nickel. B. Martin. (Proceedings of the American Electroplaters' Society, 1944, pp. 206-217). Experiments are described the purpose of which was to determine the effect of changes in the plating conditions on the residual stress in electrodeposited nickel. The stress was determined by measuring the curvature of strips of cold-rolled steel, 1 in. wide, 0.01 in. thick and 6 in. long, after plating under standard conditions. Increasing the temperature of deposition causes the residual stress to be reduced. Increasing the cathode current density increases the stress. Changes in the amounts of nickel and boric acid in the solution have practically no effect. Raising the pH value of the solution from 2.0 to about 5.0 has very little effect, but a small increase beyond 5.0 causes a marked increase in the stress. At low pH values the presence of lead, zinc, chromium or copper has little effect on the stress, whilst at high pH values lead and copper effect a reduction of stress and hexavalent chromium increases it. The formation of stress in nickel deposits is probably due to the co-deposition of hydrates.

Galvanizing. W. H. Spowers, jun. (American Society of Naval Engineers: Wire and Wire Industry, 1945, vol. 20, June, pp. 420-427, 451-453). A description is given of the galvanising equipment and process at a United States Navy Yard. The plant includes a centrifuge for removing surplus zinc from galvanised parts. This centrifuge attains a speed of 900 r.p.m. in 10 sec. and will deal with a basketful of parts (160 lb. gross) in $1\frac{1}{2}$ min. The results of tests of the time required to pickle steel in sulphuric acid of various concentrations at temperatures of 77°, 105°, 120°, 150° and 180° F. are reported. At 77° F. 25% sulphuric acid pickled in the shortest time. An increase from 40% to 50% in the concentration increased the pickling time from 13 to 30 min. The most practical and economical concentration appeared to be 5% sulphuric acid at 120-150° F.

Technics of Tins. R. T. Colgate. (Chemistry and Industry, 1945, June 16, pp. 186-188). A review of the development of the tinplate industry is presented with special reference to the electrolytic tinning of steel strip.

Glass-Lined Steel Fabrication. G. L. Dawson, jun. (Steel Processing, 1945, vol. 31, Apr., pp. 231-237). The fabrication by welding of large cylindrical vessels of low-carbon steel and the method by which the interior is lined with glass are described and illustrated.

Lead Coated Steels Appraised. (Iron Age, 1945, vol. 155, May 24, pp. 56-57). The advantages and limitations of lead coatings on steel and the possibilities of substituting them for terne and galvanised sheets are discussed. An efficient method of stripping lead and lead-alloy coatings is also described.

Studies on the Adherence and Corrosion Resistance of Silver Plate on Steel. F. C. Mesle. (Proceedings of the American Electroplaters' Society, 1943, pp. 33-36). Tests are described which illustrate the effect of heating and of holding time on the adherence of silver electroplated on steel and on nickel and copper coatings on steel. Increasing the holding time at temperatures in the 400-1400° F. range reduced the adherence of silver plated on nickel, whilst increasing the thickness of the silver coating increased the bond. Specimens of silver-plated steel and others with an intermediate strike of copper were heated at 350° F. in oil and at 600° F. in air for 1 hr. without weakening of the bond. At 800° F. and at higher temperatures the adherence decreased. Tests on specimens which were silver-plated on top of a phosphate coating indicated that this combination reduced both the adherence and the corrosion resistance.

The Blueing of Steel. M. H. Stewart. (Australian Institute of Metals: Australasian Engineer, 1945, vol. 44, June 7, pp. 54-56). The equipment and the preparation of solutions for blueing gun-barrels and small arms are described.

The Black Oxide Treatment of Steel. W. H. Price, jun. (Proceedings of the American Electroplaters' Society, 1943, pp. 87-90). The equipment and process for producing a black coating of magnetic oxide (Fe_3O_4) on steel are described and the advantages of the treatment are discussed. Strictly speaking, the oxide is not a coating, as it does not increase the thickness of the steel; it penetrates to a depth of 0.001-0.0015 in.

Blackened Stainless Steels. P. B. Strassburger. (Metals and Alloys, 1945, vol. 21, May, pp. 1309-1312). Details are given of a process for blackening stainless steel so that the surface is non-reflecting while the corrosion resistance remains unimpaired. It consists of treating the part for about 15 min. in a bath of sodium dichromate at 730-750° F.

Iridite Treatment for Plated Parts. J. Albin. (Iron Age, 1945, vol. 156, May 24, pp. 44-50). Iridite is the trade name for a chemical mixture which is applied to cadmium or zinc-plated surfaces and to hot-dipped galvanised parts and zinc die castings. By forming a coating of a semi-

hard amorphous character it excludes air and moisture from the metal surface thus protecting the cadmium or zinc plate. Iridite corrosion-resistant surfaces can be obtained in several colours and finishes.

Industrial Paint Coatings. W. H. Lutz. (Proceedings of the American Electroplaters' Society, 1943, pp. 78-80). The properties and characteristics of the ingredients of paints for industrial purposes are discussed.

PROPERTIES AND TESTS

(Continued from pp. 90 A-95 A)

High Strength Steels Pace Lightweight Development. F. D. Foote. (Iron Age, 1945, vol. 155, June 14, pp. 61-65, 124-148). The characteristics of the high-tensile steels and the particular industrial applications for which they are most suitable are discussed. Special reference is made to the uniform and tightly adhering coat of rust which forms on them and prevents further corrosion. Plates of high-tensile steel can therefore be used to save weight where the factor of corrosion resistance is more important than the extra strength.

The Effect of the Matrix Structure and Graphite Inclusions on the Properties of Cast Iron. G. Meyersberg. (Svenska Metallografförbundet : Teknisk Tidskrift, 1945, vol. 75, June 9, pp. 641-654). (In Swedish). The theories put forward in the author's earlier paper on the relation between the mechanical properties and the structure of cast iron (see Journ. I. and S.I., 1936, No. II., p. 131 A) are developed with special reference to the manner in which the graphite particles reduce the tensile strength, elongation, and modulus of elasticity.

Cast Iron and Its Relation to Machine Tools. P. A. Russell. (Journal of the Institution of Production Engineers, 1945, vol. 24, July, pp. 180-188). This is for the main part a repetition of a paper presented in 1939 (see Journ. I. and S.I., 1940, No. II., p. 119 A) with the addition of one or two new points. Some machinability tests using a tungsten-carbide-tipped drill indicated that neither the tensile strength nor the Brinell hardness of the work is a true guide to machinability.

The Effect of the Angles of Welding Seams to the Direction of Stress on Tensile Strength. H. Zschokke and R. Montandon. (Schweizer Archiv für angewandte Wissenschaft und Technik, 1944, vol. 10, May, pp. 129-137). The effect of the direction of a weld at different angles across a flat tensile specimen and of shallow and deep grooves cut at different pitches round the surface of hollow steel cylinders subjected to pressure tests was investigated. With the flat specimens the fracture was always through the parent metal, and was unaffected by the direction of the weld. In bursting tests on the hollow cylinders the direction of the fracture was unaffected by the direction of a shallow groove except when the groove was at 60° to the axis, in which case the fracture followed the groove. With deep grooves reducing the tube wall by 60%, the fracture always occurred in the groove. The results indicated that minor faults in the welding of pressure vessels subjected only to static stresses are not so dangerous as is generally supposed, but they cannot be tolerated where alternating stresses are imposed.

Residual Stress Study. R. W. Greaves, E. C. Kirstowsky, and C. Lipson. (Proceedings of the Society for Experimental Stress Analysis, 1944, vol. 2, No. 2, pp. 54-58). Carburising, nitriding, grinding and superfinishing are frequently used in fabricating aero-engine crankshafts and gears; these operations cause residual stresses. This paper reports the results of measurements of these residual stresses in rings of case-hardened and

nitrided steels surface-finished in various ways. The stresses were calculated from measurements of the strain after cutting through the circumference of the rings.

Electric Gaging Methods : Their Selection and Application. H. C. Roberts. (Proceedings of the Society for Experimental Stress Analysis, 1944, vol. 2, No. 2, pp. 89-94).

A New Method for the Micro-Mechanical Testing of Metals. N. Mironoff. (*L'Ossature Métallique*, 1945, vol. 10, Mar.-Apr., pp. 73-75). An illustrated description is given of a novel appliance for making bend tests on very small specimens of sheet metal up to 3 mm. thick. It consists of two short levers on a single pivot; each lever carries a pair of jaws, one pair rigidly holding one end of the specimen and the other pair acting as guides for the other end of the specimen. Adjustable stops are provided which limit the movement of the levers on the pivot, so that the specimen can be bent backwards and forwards through an angle of 45°, 60°, 75° or 90°. The number of bends a specimen can be given before fracture is a measure of its ductility.

The Magnetic-Coupled Torquemeter. B. F. Langer and K. L. Womack. (Proceedings of the Society for Experimental Stress Analysis, 1944, vol. 2, No. 2, pp. 11-16). A detailed description is given of a magnetic-coupled torque meter for testing supercharger and gas-turbine shafts. It applies the principles of the magnetic strain gauge without using slip rings.

Notch Impact Tests. C. F. Keel. (*Welding*, 1945, vol. 13, July, pp. 242-247, 252). An abridged translation is presented of a report published in the Swiss journal *Zeitschrift für Schweisstechnik* (November, 1944). The results of notch-impact tests on gas welds in German and Swiss investigations are reviewed. In tests on vertical welds it was found that a brief normalising treatment with the blowpipe greatly improved the notch-impact values obtained.

Clean Steel. (*British Steelmaker*, 1945, vol. 11, June, pp. 261-266). The effects of non-metallic inclusions and streaks on the results of tensile and impact tests, and the effect of notches in the rolled face and the unrolled edge of flat specimens for Izod tests are discussed.

Studies of Plastic Flow Problems by Photo Grid Methods. C. P. O'Haven and J. F. Harding. (Proceedings of the Society for Experimental Stress Analysis, 1944, vol. 2, No. 2, pp. 59-70). In Part I. of this paper new methods of preparing a dichromate polyvinyl alcohol solution and applying this photo-sensitive coating to specimens of various shapes, and of printing and developing the grid are described. In Part II. the application of the process to study plastic deformation in tensile specimens of various shapes is illustrated by examples.

The Yielding Phenomenon of Metals. Influence of Speed and Loading Conditions. G. Welter. (*Metallurgia*, 1945, vol. 31, Jan., pp. 144-150; Feb., pp. 207-212; Mar., pp. 263-268; Apr., pp. 309-315; vol. 32, May, pp. 31-36; June, pp. 80-84). Theoretical considerations and other factors which have a pronounced influence on the yielding of metals in tensile tests were investigated. In particular, the effect of the type of testing machine and the rate of plastic deformation were examined. A new direct-loading machine with a special recorder was designed, and the stress-strain diagrams obtained with it were compared with those obtained with a rigid testing machine. The axial transmission of the load to the specimen was ensured by using new types of universal joint. The behaviour of metals during yielding in both types of testing machines was studied using a device based on the sliding friction between three plates screwed together. It was found that: (1) The shape of the stress-strain curve depends very much on the type of testing machine; (2) The yielding of metals as recorded by the rigid straining machine does not accord with the true behaviour of

the specimens; (3) the sudden decrease in the load at the beginning of the yielding is an effect of the rigid straining machine; (4) in the direct-loading machine no upper and lower yield points were recorded as the total yield took place instantaneously at a single critical load; and (5) ordinary extensometers are quite unsuitable for testing at very fast rates of elongation which approach dynamic testing conditions.

Metallurgical Studies of Rails. H. O'Neill. (Institution of Civil Engineers, 1945, Railway Paper No. 15). A detailed metallurgical study of a typical medium-manganese steel rail is presented and a proposal for a chart to record rail failures is made. Finally, some methods of dealing with "wheel slide exfoliation," corrosion, wear, the freezing of points and internal stress effects are discussed.

How Does Propagation of a Small Crack Take Place in Thin Plates? L. E. Grinter. (Welding Journal, 1945, vol. 24, June, pp. 319-S-320-S). When cracks occur in relatively thin welded steel plates it is generally found that the first portion of the crack is a slipping shear fracture, whilst this extends at each end with a brittle herring-bone type of fracture. A mathematical analysis is made which supplies an explanation of this.

Improving the Weldability of High Strength, Low Alloy Steels. S. I. Hoyt, C. E. Sims, and H. M. Banta. (Iron Age, 1945, vol. 155, May 31, pp. 38-46; June 7, pp. 70-76; June 14, pp. 74-80, 148). The combined effect of sulphur and aluminium on the porosity and crack sensitivity of welds on small panels of normalised and tempered cold-rolled steel containing 1% of chromium and 0.20% of molybdenum was investigated. Five small electric-furnace heats with sulphur contents ranging from 0.012% to 0.047% were prepared, from each of which six ingots were cast; the six ingots were deoxidised with different amounts of aluminium. As much as 6 lb. of aluminium per ton of steel may be added without any increase in the porosity of welds, provided that the sulphur content does not exceed 0.012%. Contrary to expectation, the weld-crack sensitivity decreased with increasing sulphur content; this decrease was more pronounced in the higher aluminium steels. A quantitative study was also made of the crack-sensitivity and hardness resulting from carefully controlled preheating and postheating cycles.

Zinc-Saboteur of Steel at Elevated Temperatures. F. Page, jun. (Proceedings of the American Electroplaters' Society, 1943, pp. 51-54). Experiments are described which demonstrate that when stressed steel comes in contact with molten zinc the iron at the grain boundaries in the area in tension dissolves in the zinc much more rapidly than the unstressed material; this leads to crack formation and failure. Stainless steel is not immune from this, and a piece of 16 gauge stainless steel has been known to break in less than 1 sec. by the action of molten zinc.

Shot Peening to Improve Fatigue Resistance. O. J. Horger and H. R. Neifert. (Proceedings of the Society for Experimental Stress Analysis, 1944, vol. 2, No. 2, pp. 1-10). The manner in which the conditions of shot-peening affected the improvement in the fatigue strength of 1½-in. dia. bars of 0.45% carbon steel was investigated. A maximum increase in the endurance limit of 54% as compared with polishing was noted. Mechanical and pneumatic shot-blasting improved the endurance limit by approximately equal amounts, but the former required less time than the latter.

A New Type of Hardness Testing Machine. (Foundry Trade Journal, 1945, vol. 76, July 26, pp. 264, 267). An illustrated description is given of a new Brinell hardness testing machine capable of applying loads of from 250 to 3000 kg. at a controlled rate. Tests requiring a high degree of precision, as well as routine tests, can be carried out on the same standard machine.

The Determination of the Hardness of Martensite and Austenite by Means of the Microhardness Tester. H. Hanemann. (*Metallurgia*, 1945, vol. 32, June, pp. 62-65). An English translation is presented of a paper which appeared in *Archiv für das Eisenhüttenwesen*, 1942, vol. 18, Mar., pp. 403-406 (see *Journ. I. and S.I.*, 1943, No. I., p. 214 A).

Sources of Error in Diamond Pyramid Hardness Measurements on Hardened Steel. W. N. Hindley. (*Iron and Steel Institute*, 1945, this *Journal*, Section I). The purpose of this work was to determine the extent to which the results of diamond pyramid hardness (H_D) tests carried out by independent observers on hardened steel could be relied upon, experience having shown that some observers reported widely different results on material of the same nominal composition and heat-treatment. The conclusions apply generally to all hardness testing. As materials or components are sometimes accepted only to a given H_D specification, it is important that the H_D figures obtained should be reliable. Wide variation in the results reported by independent observers was found, although results within close limits of agreement were obtained on the same samples by an experienced observer, when care was taken in the preparation of the flats. The wide variations obtained are attributed to carelessly prepared flats, and a standardised procedure for surface preparation is therefore recommended.

Hardenability and Interchangeability of Cast Steels. H. A. Schwartz. (*Iron Age*, 1944, vol. 154, Nov. 23, pp. 42-46). The results of many tests are presented by plotting the ideal critical diameter found by the Jominy end-quench test against the tensile strength, elongation and impact strength for several medium-carbon low-alloy steels. From these the author concludes that the mechanical properties of two steels cannot be presumed to be similar when the hardenabilities are the same.

The Jominy Hardenability Test. E. W. Cox. (*Australian Institute of Metals: Australasian Engineer*, 1945, vol. 44, June 7, pp. 56-57). A detailed description of the Jominy end-quench test is given and some examples of its practical application are discussed.

The World's Largest Permanent Magnet. E. N. Simons. (*Australasian Engineer, Science Sheet*, 1945, June 7, pp. 4-5). A description is given of a very large permanent magnet made of 35% cobalt steel which was designed for the investigation of β -ray spectroscopy at the Cavendish Laboratory, Cambridge. Each arm of the magnet consists of 23 laminations, each measuring 42.4 cm. \times 14.6 cm. \times 1 cm. The air gap is 5.5 cm. Constancy of the magnetic field was essential, and in one experiment the field of 82 gauss remained constant to the same accuracy for 4½ days.

Magnetic-Particle Testing Stations Reveal Surface Defects Rapidly. F. W. Rohde. (*Machinist*, 1945, vol. 89, June 30, pp. 397-400). The system of inspecting parts for aero-engines adopted by the Jacobs Aircraft Engine Company is described and illustrated. The methods used include Magnaflux, Magnaglo and Zyglo. In the Magnaglo and Zyglo processes fluorescent pastes are used. The Zyglo process is for non-ferrous metals and austenitic steels.

Magnetic Powder Inspection of Castings. C. L. Frear. (*American Society for Testing Materials: Foundry*, 1945, vol. 73, June, pp. 104-107, 272-278). See *Journ. I. and S.I.*, 1945, No. I., p. 156 A.

Temper Brittleness and Heat Embrittlement of Alloy Steels. P. B. Michailow-Michejew. (*Iron and Steel Institute*, 1945, Translation Series, No. 234). An English translation is presented of a paper which appeared in *Archiv für das Eisenhüttenwesen*, 1944, vol. 17, Jan.-Feb., pp. 177-184 (see *Journ. I. and S.I.*, 1945, No. I., p. 137 A).

Strength of Steels at High Temperatures. (*Engineering and Boiler House Review*, 1945, vol. 59, Apr., pp. 82-87; June, pp. 144-147). Several

recent papers on methods of testing steel at high temperatures are reviewed, and the results of creep tests and fatigue tests at high temperatures are discussed.

Influence of Alloying Elements in Cr-Ni-Mo Steel. V. M. Doronin. (Stal: Iron Age, 1944, vol. 154, Aug. 3, pp. 65-67). An abridged translation is presented of a paper which appeared in the Russian journal Stal, 1943, No. 1-2; it deals with the changes in the mechanical properties and hardening characteristics of low-alloy chromium-nickel-molybdenum steels with small changes in the amounts of the alloying elements present.

How the Hercules Powder Co. Purchases Stainless Steels. W. L. Hewes. (Steel, 1945, vol. 117, July 9, pp. 100-101, 134-154). Acceptance tests developed by a chemical manufacturing company purchasing stainless-steel tubes, plates and tanks are described.

Standardization of Shackles. (Iron Age, 1945, vol. 156, July 12, pp. 50-54). As a result of the failure of a shackle in a wire rope sling at a Wilmington shipyard, all the shackles at this shipyard were tested by applying a load and by the Magnaflux method. A test specification for shackles and a method of reporting failures, based on the experience gained, are proposed.

CORROSION OF IRON AND STEEL

(Continued from pp. 97 A-99 A)

Theory of Stress Corrosion Cracking of Mild Steel in Nitrate Solutions. J. T. Waber, H. J. McDonald, and B. Longtin. (Electrochemical Society, 1945, Preprint No. 32). An account of the investigation reported in this paper has already been published in Welding Journal, 1945, vol. 24, May, pp. 268-S-273-S (see p. 97 A).

Stress Corrosion of Cast Irons. R. F. Hehemann, D. A. Shepard, and L. Thomassen. (Metals and Alloys, 1945, vol. 19, May, pp. 1141-1144). Specimens of grey cast iron, malleable cast iron and austenitic cast iron containing chromium 1.5% and nickel 18% were subjected to tensile and bending stresses while surrounded by a 50% solution of sodium hydroxide at 270° F. The test results indicated that austenitic cast iron must be regarded as brittle under stress-corrosion conditions. The malleable cast iron offered the greatest resistance to the test conditions and was unaffected after 350 hr. exposure, whilst some austenitic specimens failed in 1-3 hr.

Result of Stabilizing Heat Treatment on Welded 18-8 Stainless. W. G. Hubbell. (Iron Age, 1945, vol. 155, June 21, pp. 56-60; Iron and Steel, 1945, vol. 18, July, pp. 230-234). The corrosion of aero-engine exhaust manifolds made of welded 18/8 stainless steel stabilised with columbium and titanium was investigated. It was found that heat-treatment at 1650° F. for 30 min. did not improve the resistance to attack by exhaust gases, but slightly increased the resistance to corrosive aqueous solutions and electrolytes.

Effect of Aeration on Hydrogen-Ion Concentration of Soils in Relation to Identification of Corrosive Soils. M. Romanoff. (Journal of Research of the National Bureau of Standards, 1945, vol. 34, Mar., pp. 227-241). The unreliability of air-drying samples of soils to obtain comparable results in the measurement of the pH value is pointed out. Sixty-two air-dried samples of soils were saturated and stored without air for almost one year. Significant changes in the pH values were observed in most cases and large changes in many of them. For the identification of areas corrosive to iron and steel, pH measurements of soils should be made on samples maintained in the natural field condition.

Methods of Polishing Steel and Their Effects upon the Protective Value of Electroplated Coatings. G. A. Lux and W. Blum. (Journal of Research of the National Bureau of Standards, 1945, vol. 34, Apr., pp. 295-324). Strips of cold-rolled steel were polished with abrasive wheels of different grain size and the finishes obtained were measured with a profilometer. The polished specimens were plated with copper, nickel and chromium of controlled thickness. They were then exposed for long periods and the extent of the rusting was observed by periodic inspections. The wide differences in the surface finish had no significant effect on the protective value of the plated coatings.

Diagnostic Methods in Problems Concerned with the Corrosion of Food Cans. W. B. Adam and D. Dickinson. (Society of Chemical Industry: Sheet Metal Industries, 1945, vol. 21, May, pp. 824-826; June, pp. 1009-1010). See Journ. I. and S.I., 1945, No. I., p. 115 A.

Laboratory Corrosion Tests. R. M. Burns. (Industrial and Engineering Chemistry, Analytical Edition, 1945, vol. 17, May, pp. 299-302). Corrosion testing equipment and procedures for laboratory investigations are reviewed with descriptions of the more common tests of the following types: Total immersion, atmospheric, salt-spray, electrochemical, and soil tests.

BOOK NOTICES

(Continued from pp. 101 A-102A)

BROOKE, E. H. "*Chronology of the Tinplate Works in Great Britain.*" 8vo, pp. 177. Cardiff, 1944: William Lewis (Printers), Ltd. (Price 8s.)

This chronology is a fuller and more interesting history than the "Monograph" published in 1932, and brings up to date extracts from the records of the author and his father, C. B. Brooke, regarding every tinplate works (and certain closely associated steel and galvanising plants) which have been kept for an unbroken period of eighty-one years. It also includes references to specific tinplate works which have appeared in the literature published in the 18th and 19th centuries. The plant, the weekly capacity, the brands used, the extensions carried out, and the changes in the administration of each works (arranged alphabetically) are shown from the date of foundation. The works are also listed in chronological order under districts. In addition tables are presented showing the estimated total production (in boxes) from 1830 to 1938, the estimated home consumption, and the exports. The average selling prices of tinplates and tin from 1849 to 1943 are given. Also included in the book are particulars of the International Tinplate Cartel and the International Tin Control.

MALLEABLE FOUNDERS' SOCIETY. "*American Malleable Iron. A Handbook.*" 8vo, pp. viii + 367. Illustrated. Cleveland, 1944: The Society.

The term "malleable cast iron" for the product described in this book is, according to the editors, a misnomer, and has been replaced by the name "American malleable iron," which it is claimed is accurate in distinguishing the product both from grey iron materials and from the European whiteheart malleable iron. The essential difference between American malleable iron and European whiteheart malleable iron is that heat-treatment of whiteheart aims at decarburisation, whereas heat-treatment of American blackheart effects graphitisation. One misleading idea is that thick sections of American malleable iron will not anneal. This is true for whiteheart malleable, because decarburisation proceeds slowly inward from the outer surface, but it is not true for American malleable, because graphitisation is an internal phenomenon occurring throughout the metal when the graphitising temperature has been reached.

The book opens with a brief outline of the history of malleable iron castings and the work of Réaumur in Europe and Boyden in America. Succeeding chapters, describe fully the properties of standard malleable irons, pearlitic malleable irons,

special malleable irons, and cupola malleable iron. Chapters are devoted to the design of castings and patterns, machining practice, and recommendations to users of malleable iron castings. The manufacture of malleable iron and the metallurgy of the process are discussed, and a sketch is given of the history of the American malleable iron industry, which produced 975,000 tons of castings in 1943. Representative applications of the material are described and the major industrial and commercial fields in which it is employed are classified. Appendices are included which give particulars of the A.S.T.M. specifications for malleable iron castings, techniques to be followed in the application of protective coatings, a selected bibliography of the literature on the effect of alloys in malleable iron, the conditions governing the quotation and sale of malleable iron castings, and a glossary of terms used in the industry.

In the compilation of this volume, which is profusely illustrated, the editors have drawn freely on all available sources, and a bibliography of the literature consulted is given. At the end of the volume are included many useful engineering tables and data.

"*Svedberg, The, 1884-1944.*" 8vo, pp. 731. Illustrated. Uppsala, 1944.

This volume is dedicated to The Svedberg, Professor of Physical Chemistry at the University of Uppsala, on the attainment of his sixtieth birthday. Professor Svedberg has made a number of important contributions on chemical problems with industrial applications, establishing close connections between academic science and industrial research to an extent unprecedented in Sweden. The book was planned and written during the war, and it was not considered right to ask for contributions from scientists in other countries who were engaged on other work of immediate importance. The contributions, a large number of which originate from Professor Svedberg's own Institute, cover a wide range and give to a certain extent a cross-section of Swedish activities in chemical research during the difficult years of the war.

TRUBIN, K. G. "*Fundamental Problems Relating to the Quality of Steel Ingots.*" (Scientific Engineering Technical Society of Metallurgists of the East. Steel-Casting Section.) Sm. 8vo, pp. 80. Sverdlovsk and Moscow, 1943. [In Russian.]

This booklet is based on a paper prepared by Professor Trubin at the request of the Institute of Metallurgy of the Academy of Sciences of the U.S.S.R., for a symposium on the quality of ingots which was to have been held in 1941, but was abandoned because of the war.

The author surveys the investigations that have been carried out on the different factors affecting the structure of steel ingots, and summarises the various theories that have been advanced from the results of such investigations. The subject is covered in six chapters. The first of these deals with the solidification of steel, the structure of liquid steel, the mechanism of crystallisation, the formation of dendrites, periodic phenomena in the crystallisation of steel, the development of the axial zone, and the rate of crystallisation in the mould. The rate of cooling of an ingot and factors affecting it are dealt with from the point of view of their possible influence on dendritic crystallisation. In the following chapter, which deals with segregation, an account is given of the theories of Hayes and Chipman, of Hultgren and Phragmén, and of Andrew. In connection with segregation in ingots, reference is also made to change in the composition of the steel in the ladle during teeming, a subject that has been investigated by the author. The third chapter surveys factors influencing the physical and chemical heterogeneity of ingots of killed steel, *e.g.*, melting practice, the material and shape of the mould, chemical composition of the metal, rate of teeming, the use of hot-tops and of heat-generating covering compounds and the effect of the mechanical agitation of the solidifying metal. There is also a section dealing with the segregation of non-metallic inclusions. The fourth chapter is concerned with the physical and chemical heterogeneity of rimming steel ingots, with particular reference to the nature and cause of the blowholes, and the effect of the composition of the steel on its structure. The segregation of alloying constituents and of non-metallic inclusions in rimming steel ingots are also dealt with. The influence of melting practice, chemical composition of the metal, deoxidation practice and of methods of pouring on the characteristics of rimming and semi-killed steel ingots is dealt with in the fifth chapter. The segregation in semi-killed steel is discussed in a short concluding chapter.

Though referred to as a critical survey, the author's criticisms are restricted to pointing out here and there the need for further research where the divergences

between the results, conclusions and theories of the different investigations of some special problem are particularly striking. In the absence of any extensive discussion of the subject-matter surveyed, the booklet can be regarded primarily as a handy work of reference, its usefulness in that direction being indicated by the list of eighty-one references to items dealt with in the text. Among these the various Reports of the Committee on the Heterogeneity of Steel Ingots occupy pride of place, and there is also a fair proportion of references to Russian publications, some of which, however, are probably unobtainable in this country.

A. BEHR.

BIBLIOGRAPHY

(Continued from pp. 74 A-75 A)

- AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS. "*Electric Furnace Conference.*" Sponsored by The Electric Furnace Steel Committee of the Iron and Steel Division, American Institute of Mining and Metallurgical Engineers. *Proceedings* Volume 2, Pittsburgh Meeting, October 5-6, 1944. 8vo, pp. 464. Illustrated. New York: The Institute.
- BELCHER, R., and A. L. GODBERT. "*Semi-Micro Quantitative Organic Analysis.*" 8vo, pp. viii + 168. Illustrated. London, 1945: Longmans, Green and Co. (Price 10s. 6d.)
- BEYNON, C. E. "*The Physical Structure of Alloys.*" An Introduction to Modern Physico-Chemical Theories. Sm. 8vo, pp. 126. Illustrated. London, 1945: Edward Arnold and Co. (Price 6s. 8d.)
- BRITISH NON-FERROUS METALS RESEARCH ASSOCIATION. "*Collected Papers on Metallurgical Analysis by the Spectrograph.*" Edited by D. M. Smith. 8vo, pp. xi + 162. Illustrated. London, 1945: The Association. (Price 21s.)
- EVE, A. S., and C. H. CREASEY. "*Life and Work of John Tyndall.*" 8vo, pp. xxxii + 404. London: Macmillan and Co., Ltd. (Price 21s.)
- HOARE, W. E., and E. S. HEDGES. "*Tinplate.*" La. 8vo, pp. viii + 292. Illustrated. London, 1945: Edward Arnold and Co. (Price 40s.)
- INSTITUTE OF ECONOMIC ENGINEERING. "*Time Study and Rate-Fixing.*" Edited by The Institute of Economic Engineering. This publication is based on Lectures given by F. L. Meyenberg from May to September 1943. 8vo, pp. xxi + 225. Illustrated. London, 1945: The Engineers' Digest and Sir Isaac Pitman and Sons, Ltd. (Price 20s.)
- KOEHLER, W. A. "*Principles and Applications of Electrochemistry.*" Vol. 2. "*Applications.*" Second Edition. 8vo, pp. v + 573. New York, 1945: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd. (Price 30s.)
- MANLEY, R. G. "*Waveform Analysis.*" A Guide to the Interpretation of Periodic Waves, including Vibration Records. 8vo, pp. xi + 275. Illustrated. London, 1945: Chapman and Hall, Ltd. (Price 21s.)
- MATTIELLO, J. "*Protective and Decorative Coatings.*" First Edition, pp. 349. Washington, D.C., 1945: U.S. Government Printing Office.
- MAY, E. C. "*Principio to Wheeling 1715-1945.*" A Pageant of Iron and Steel. 8vo, pp. 535. New York, 1945: Harper and Bros. (Price \$3.)
- PARKER, H. "*Simplified Design of Structural Steel.*" 8vo, pp. x + 226. Illustrated. New York, 1945: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd. (Price \$2.75.)
- SCHLESINGER, G. "*Testing Machine Tools.*" New Edition, 4to, pp. 102. Brighton, 1945: Machinery Publishing Co., Ltd. (Price 17s. 6d.)
- TAYLOR, A. "*An Introduction to X-Ray Metallography.*" With a Foreword by Sir Lawrence Bragg, O.B.E., F.R.S. 8vo, pp. xi + 400. Illustrated. London, 1945: Chapman and Hall, Ltd. (Price 36s.)
- TUPHOLME, C. H. S. "*Photography in Engineering.*" 8vo, pp. xv + 278. Illustrated. London, 1945: Faber and Faber, Ltd., and the Hyperion Press, Ltd. (Price 42s.)
- VOGEL, A. I. "*A Text-Book of Qualitative Chemical Analysis including Semimicro Qualitative Analysis.*" (Third Edition.) 8vo, pp. xii + 578. London 1945: Longmans, Green and Co. (Price 12s. 6d.)

ORES—MINING AND TREATMENT

(Continued from pp. 76 A—77 A)

Effect of Variables in Chemical Beneficiation of Chromite Ores. F. S. Boericke and W. M. Bangert. (United States Bureau of Mines, July, 1945, Report of Investigations No. 3817). More than 100 controlled, small-scale experiments were carried out to test certain phases of the selective reducing and leaching process for the enrichment of low-grade chromite ores mined in the United States. A roasting temperature of at least 1200° C. is required for the selective reduction of at least 60% of the iron in any reasonable time. It is advantageous to have the chromite screened below 28 mesh in order to shorten the roasting time and decrease the chromium loss. The rate of reduction and the amount of extractable iron appear to be independent of the alumina and silica contents of the ore (within the limits of the compositions studied).

Beneficiation of Iron Ores by Flotation. Part I. Anionic Flotation of Silica from Calcareous Red Iron Ores of the Birmingham District, Alabama. J. B. Clemmer, B. H. Clemmons, C. Rampacek, M. F. Williams, jun., and R. H. Stacy. (United States Bureau of Mines, Mar., 1945, Report of Investigations No. 3799). Although the "caustic-metaphosphate" method appears to be the ideal one for beneficiating the calcareous red iron ores of the Birmingham district (Alabama), where rejection of the quartz and recovery of the hematite and calcite in an enriched product suffice for treatment, the method does not cure all the troubles of iron-ore flotation. The method is at its best on iron ores containing naturally activated siliceous gangue. It is applicable to many siliceous iron ores that require prior activation of the siliceous materials by the judicious use of a good activating agent. Activation and anionic flotation of the silica have given moderately good results in the laboratory on many siliceous ores of the Birmingham and Lake Superior districts. Certain ores, however, failed to respond to treatment. The ores containing more or less earthy oxides responded to separation more readily than those containing specular hematite or magnetite. A continuation of the laboratory study has recently resulted in the development of a more attractive method for the flotation of iron ores containing specularite or magnetite. A description of this method will be the subject of a later report.

How Republic Concentrates Adirondack Iron Ores. (Engineering and Mining Journal, 1945, vol. 146, July, pp. 90-93). A brief description is given of the wet magnetic concentration plant and the sintering plant, erected near Port Henry for the Republic Steel Corporation, to concentrate the magnetite ores of the Adirondack Mountains.

Physical and Chemical Phenomena in the Sintering of Iron Ores. F. Hartmann. (Stahl und Eisen, 1943, vol. 63, May 20, pp. 393-398). An investigation was carried out with the object of improving the sintering process by ascertaining the optimum composition, screen analysis and humidity of the ore, and the proportion of fuel required. It was found that sintering consists first of a reduction process, which is followed, after passing a maximum temperature, by oxidation. The reduction process lowers the melting point and the sintering temperature; the temperature of the plastic phase is probably also reduced. The same is true for the viscosity range. The melting temperature range of the ores is lowered by the reduction to such an extent that the mixture becomes very fluid at 1100-1300° C. The ore particles combine into drops, and the mass becomes porous like a sponge. The air easily permeates it, and thus

assists combustion. Should this state continue, the whole mass would drop and form a dense layer impervious to air, thus checking the process. Trouble of this kind occurs in full-scale operations. When the reduction changes into oxidation the melting point of the spongy mass rises again. The temperature at which the mass becomes viscous rises above 1450°C. , and the sinter solidifies, this being assisted by the air. The carbon content of the mixture has to be adjusted so as to cover the heat requirements for melting, liquefaction and reduction, but it should not prolong the reduction nor delay the oxidation which is necessary for the resolidification. There is an optimum proportion of fuel for every sintering mixture.

Metallurgical Methods of Increasing the Iron Recovery in the Concentration of Lean Ores. M. Tigerschiöld. (Iron and Steel Institute, 1945, Translation Series, No. 238). An English translation is presented of a paper which appeared in *Jernkontorets Annaler*, 1944, vol. 128, No. 9, pp. 423-450 (*see* Journ. I. and S.I., 1945, No. I., p. 39 A).

Modern Ore-Crushing and Classifying Plants. W. Tillmann. (*Stahl und Eisen*, 1943, vol. 63, Apr. 8, pp. 273-276). Descriptions and diagrams are presented of two ore-discharging and preparation plants of modern design which have proved to be efficient in practice. One plant discharges, crushes, screens and sinters Swedish ores arriving in lighters, whilst the other deals with ores arriving by rail.

The Standardisation of Ore Crushing, Screening and Sintering Plant Units. J. Klütsch. (Iron and Steel Institute, 1945, Translation Series, No. 229). An English translation is presented of a paper which appeared in *Stahl und Eisen*, 1944, vol. 64, Oct. 26, pp. 675-679 (*see* Journ. I. and S.I., 1945, No. I., p. 91 A).

REFRACTORY MATERIALS

(Continued from p. 103 A)

Dolomite Linings for Basic Electric Arc Furnaces. E. C. Brampton, H. Parnham and J. White. (Iron and Steel Institute, 1945, this Journal, Section I). The conditions to which the linings of arc furnaces are subjected and the development of the 100% dolomite brick and its properties are discussed. A trial with a brick roof of 100% dolomite in a 4-ton furnace which had a life of 57 heats is described; the results indicated that higher furnace temperatures can be attained and that side-wall life is materially increased. Performance data supplied by users of furnaces with 100% dolomite brick linings are given and methods of making stabilised and 100% dolomite bricks and installing the linings are described. A feature of the behaviour of 100% dolomite bricks is that, as a result of drainage and of migration of lime in the form of fusible compounds away from the hot face, the working face of the brick tends to acquire increased resistance to fluxing while in service. An X-ray analysis of used bricks showed that the zone close to the working face consisted mainly of spinel and periclase, with other divalent oxides in solid solution. Data obtained by chemical and X-ray analyses of the principal zones behind the hot face at the ends of the oxidising and reducing periods are given. The application of sulphur printing to determine the distribution of sulphides in used bricks is described; this has shown that the sulphide content is low at the hot face and reaches a maximum in certain light-coloured zones at some distance from it. Analyses of gas samples drawn from furnaces during the reducing period are presented and deductions are made from them. Samples of refining-period fume have also been analysed, and the fixed

constituents were found to consist mainly of magnesia, lime, iron oxide and silica; its composition is such that basic refractories are much less affected by it than acid refractories.

Special Brick Shapes for Cupola Refractories. H. M. Hazeltine. (American Foundrymen's Association: American Foundryman, 1945, vol. 7, July, pp. 44-45). Descriptions are given of specially shaped refractory bricks which were made for the cupola taphole, the lining below the tuyeres and to line a pouring trough 4 ft. long, 12 in. wide and 10 in. high.

Insulation of Heat-Treatment Furnaces. R. J. Sarjant. (Institute of Fuel War-Time Bulletin, 1945, June, pp. 189-200). The bearing of temperature distribution in the furnace wall on the properties of the materials used to give insulating value and mechanical stability are discussed, and a machine method of determining the temperature conditions under variable flow of heat is described. The character of the porosity and permeability in relation to the insulating value of the refractory used is studied. The mechanical properties of an insulating refractory may be subordinated to the attainment of low thermal conductivity, provided an essential standard of resistance to thermal shock is obtained. The hot strength, as revealed by the maintained under-load test, serves as a method of distinguishing between different qualities of bricks, but is not a criterion of the stability of the structure as a whole. Reliance on spalling tests is not yet practicable. Slag attack is preferably overcome by the use of cement coatings. In a broad practical sense, bulk density is a useful criterion of the value of an insulating material from the standpoint of heat storage. There are few limitations to the use of a considerable degree of insulation in heat-treatment furnaces, particularly of hot-face insulation in intermittent practice. Furnace plating or an adequate alternative is essential at present where hot-face insulation is used. Several examples are given of the application or an electrical computer to insulating problems involving the variable flow of heat.

FUEL

(Continued from p. 104 A)

The Recovery of Waste Heat from Flue Gases. (Ministry of Fuel and Power, 1945, Fuel Efficiency Bulletin No. 42). In this Bulletin, prepared by the Committee on the Efficient Use of Fuel appointed by the Ministry of Fuel and Power, the theory and practice of the recovery of waste heat from flue gases with particular reference to waste-heat boilers are concisely dealt with.

Heat Balance of Industrial Furnaces. C. S. Darling. (Mechanical World, 1945, vol. 118, Aug. 31, pp. 235-237, 247-248). Formulæ and calculations are presented for drawing up heat balances for furnaces, in particular for a furnace to heat 1 ton of forgings per hr. to 1200° C. The allocation of the total heat losses to flue gases, wall conduction and radiation through openings is calculated and the savings which can be made by insulation and the installation of a waste-heat boiler are determined.

Some Phases in the Development of Coal-Beneficiation Methods in Alabama. W. M. Mobley. (American Institute of Mining and Metallurgical Engineers, 1945, Technical Publication No. 1882). The development of coal cleaning in the Birmingham valley, Alabama, is described, with particulars of three of the seams, their washability characteristics and the equipment used.

Coal-Cleaning Performance—Comparison of Pneumatic Jig, Pneumatic Table and Baum-Type Jig. H. F. Yancey and M. R. Geer. (American 1945—ii

Institute of Mining and Metallurgical Engineers, 1945, Technical Publication No. 1888). A comparison was made of the performances of three different coal-cleaning units, a pneumatic jig, a pneumatic table and a Baum-type jig, using coal of substantially the same size mined from the same seam. The feed, clean coal and refuse from each unit were examined by screen analysis and by float-and-sink tests. The sharpness of the separation between clean coal and refuse decreased with decrease in particle size. With both pneumatic units no cleaning was accomplished in sizes finer than 28 mesh. The efficiency of separation was better with the Baum-type jig, and it was influenced much less by particle size.

The Cost of Coal Cleaning. E. S. Grumell and A. C. Dunningham. (Journal of the Institute of Fuel, 1945, vol. 18, June, pp. 147-148). This paper constitutes an appendix to the Report of the Conference on the Preparation and the Utilisation of Coal held in Manchester on February 28, 1945. A comparison is made of the costs of cleaning a "difficult" coal with 22.75% of ash and a high middlings content, and an "easy" coal with 11.3% of ash and a low middlings content. It is apparent that the losses of heat units which occur in the cleaning process are much greater than is generally realised.

Cleaning Coke-Oven Regenerators. G. A. Phillipson. (Coke and Smokeless-Fuel Age, 1945, vol. 7, Aug., pp. 148-152, 154). A description is given of a method of cleaning air and/or gas regenerators which have become partially blocked owing to the deposition of dust from blast-furnace and/or producer gas and/or air used for heating coke-ovens. The cleaning is done by blowing with compressed air at 100 lb./sq. in. through $\frac{1}{4}$ -in. dia. steel tubes 25 ft. long with specially shaped ends. The changes in the gas pressure at various points when operating with choked and with cleaned regenerators are discussed.

Recovery of By-Products in High-Temperature Coking. J. B. Reed. (British Coal Utilisation Research Association Bulletin, 1945, vol. 9, Aug., pp. 225-234). Processes of recovering by-products in high-temperature carbonisation are reviewed under the following headings: (1) Historical; (2) objects of carbonisation processes; (3) ammonia; (4) sulphur and cyanides; (5) benzole; (6) improved techniques employing pressures above or temperatures below normal; (7) coke-oven gas; (8) separation of hydrocarbons in coke-oven gas; and (9) "reformation" of coke-oven gas.

PRODUCTION OF IRON

(Continued from p. 105 A)

The Blast-Furnace Burden. T. Powell. (Metallurgia, 1945, vol. 32, July, pp. 121-125). An account is given of the difficulties encountered in the war-time operation of blast-furnaces in Great Britain. An ideal burden is described and the steps that can be taken to improve the physical condition of ore and coke to promote the optimum conditions in the blast-furnace are discussed.

Theory of Operating Blast-Furnaces at High Top Pressures. T. L. Joseph. (Chicago District and Eastern States Blast Furnace and Coke Associations: Blast Furnace and Steel Plant, 1945, vol. 33, June, pp. 699-707; Iron and Steel, 1945, vol. 18, Aug., pp. 409-414). The effects of increasing the top pressure of a blast-furnace is discussed. The direct result of increased top pressure is a substantial increase in the density and a corresponding reduction in the velocity of the gas in the upper part of the furnace. In the lower part of the furnace the relative change in absolute

pressure, and in the density and velocity of the gas, is considerably smaller. With an increase in the pressure at the top of the furnace and a constant blowing rate higher blast temperatures could be used. Experiments are described in which air was blown upwards through a column consisting of coarsely ground silica on which rested a bed of finely ground iron ore. At low rates of flow the layer of coarse particles caused the air to pass uniformly into the ore. Above a critical velocity the whole bed increased slightly in height, and a cloud of ore dust was held in suspension above the bed at places where the air formed channels through which it passed at a higher velocity than at other parts of the bed. Full-scale tests are in progress on a large blast-furnace to determine the effects of working with blowing rates up to 100,000 cu. ft./min. and at pressures up to 10 lb./sq. in. at the top of the furnace.

Study of Some Problems in the Working of Blast-Furnaces Making Basic Iron. J. Thienpont and P. Thierry. (*Revue de Métallurgie, Mémoires*, 1940, vol. 37, Sept.-Oct., pp. 201-209; Nov.-Dec., pp. 229-243). In the introduction the authors stress the importance of maintaining proper working conditions in the blast-furnace, and point out the serious troubles which may be caused in the plant by an interruption in the furnace operation. In the first part of the article, dealing with the principles of supervision of the process, they point out the necessity of examining the following factors: The slag and metal fractures, the blast pressure, the combustion zone, the top-gas temperature and the production of flue-dust. The main points which should be observed, when controlling and regulating the process, are: The ore/coke ratio, the temperature of the hot blast, and the blast volume. Next, coming to the accidental and undesirable changes in the process, the authors discuss the principal factors which impede the process, and quick methods of dealing with them successfully. In conclusion they state that the importance and frequency of interruptions in the smooth working of the furnace depend on (1) the charge, (2) the personnel, (3) the profile of the blast-furnace, and (4) the ancillary plant.

Production of Light-Weight Blast-Furnace Slag. H. O. Wicks. (*Iron and Steel Engineer*, 1945, vol. 22, July, pp. 71-75). Methods of making foamed slag are reviewed and a description is given of the Caldwell slag-granulating machine and auxiliary equipment at the works of the Hanna Furnace Corporation. The machine is rated at 60 tons per hr., and the light aggregate is finished in two sizes, one from $\frac{3}{8}$ to $\frac{1}{4}$ in. weighing 27-33 lb./cu. ft., and the other from $\frac{1}{4}$ in. to dust weighing 47-54 lb./cu. ft.

Slag Wool and Rock Wool as a Universal Substitute Material. H. Schmidt. (*Stahl und Eisen*, 1943, vol. 63, May 6, pp. 360-365). The technical and commercial aspects of slag-wool manufacture are discussed. Information on its properties and many applications in buildings and for thermal insulation is given. The manufacture of slag wool and of wool from certain natural rock in the United States is described.

Recovery of Industrial Waste Products and Residues. I. In Italy. II. In the U.S.A. M. L. Descroix. (*Revue de Métallurgie, Mémoires*, 1940, vol. 37, May, pp. 134-145; July-Aug., pp. 192-199; Sept.-Oct., pp. 225-227). After pointing out the importance of the recovery of industrial waste products and residues, the author reviews recent methods used for this purpose. He first deals with the results obtained in this direction in Italy in the working of blast-furnaces, steel melting shops, rolling-mills, and iron and non-ferrous-metal foundries. He also shows the possible economy in the production and refinement of non-ferrous metals, in the use of refractory materials and fuels, and in the utilisation of metals. Waste problems of the iron and steel and non-ferrous smelting industries in the U.S.A. are then discussed. The uses to which blast-

furnace slags, flue-dust, waste gases, and coke-oven by-products are put are described. Special attention is paid to the problem of neutralising waste liquor from pickling installations in sheet mills; the recovery of materials from waste pickle liquors is also described.

Equilibrium in the Reduction of Ferrous Chromite by Hydrogen and Energy Requirements in the Selective Reduction of Iron in Chromite. F. S. Boericke and W. M. Bangert. (United States Bureau of Mines, June, 1945, Report of Investigations No. 3813). A method of making substantially pure, synthetic ferrous chromite is described. Equilibria in the selective reduction of the iron in ferrous chromite by hydrogen were measured in the temperature range 1575-1690° K. The results were treated thermodynamically to obtain the heat and free energy of formation of ferrous chromite. Hydrogen was shown to be an ineffective reducing agent for chromite at temperatures up to 1700° K., the maximum amount reacting before equilibrium is reached being about 10%. The thermodynamic values of ferrous chromite are applied in calculations of selective reduction with carbon, carbon monoxide and methane. The calculations showed that: (1) Carbon is a potentially effective, selective reducing agent at temperatures above 1220° K.; (2) carbon monoxide is an ineffective, selective reducing agent at temperatures up to 1700° K.; and (3) methane is a potentially effective selective reducing agent at temperatures above 1200° K. The heat, free energy and equilibrium-constant equations and values are derived for the reactions with these three reducing agents.

Effects of Pressure and Temperature on Iron Powder Compacts. C. O. Heath, jun., and J. D. Stetkewicz. (Metal Progress, 1945, vol. 48, July, pp. 73-76). Experiments are described in which cylindrical compacts of iron powder were sintered at different pressures and temperatures. Curves are presented showing the relationship of temperature to density, temperature to hardness, and pressure to reduction in diameter during sintering. All the specimens were sintered for 1 hr. in hydrogen. The variations due to changes in pressure were of greater magnitude and were more consistent than those due to temperature. When high density, hardness and strength are desired there is no advantage in sintering at above 900° C. When dimensional change or shrinkage is of major importance the optimum sintering temperature is 950-1000° C.; variations in pressure then have little or no effect on the change in cross-section. For high hardness the lower sintering temperatures give the better values, especially for pressures above 40 tons/sq. in.

Powder Metallurgy. G. H. S. Price. (Journal of the Electrodepositors' Technical Society, 1945, vol. 20, pp. 147-154). A brief general review of powder metallurgy, with particular reference to the types and properties of the powders used, is given.

FOUNDRY PRACTICE

(Continued from pp. 106 A-107 A)

Pearl Harbor Foundry Keeps Navy Ships Fighting. E. C. Kreutzberg. (Foundry, 1945, vol. 73, July, pp. 104-109). An illustrated description is given of the equipment at the foundry of the United States Navy at Pearl Harbour, where iron and steel castings up to 20 tons in weight can be produced.

Theories of Gray Cast-Iron Inoculation. H. W. Lownie, jun. (American Foundrymen's Association: American Foundryman, 1945, vol. 7,

July, pp. 57-63). Three types of graphite flake distribution in grey cast iron are described; these are: Type *A*, with large flakes dispersed at random through the pearlite matrix, type *D*, a fine interdendritic segregation with random orientation, and type *E*, also between the dendrites, but with preferred orientation. The purpose of inoculation is to promote the formation of type *A* graphite and suppress the formation of types *D* and *E*. Three theories which are advanced to explain the effect of inoculants are discussed. According to the graphite nuclei theory the addition of fine graphite to the iron in the ladle provides more nuclei for the formation of type *A* flakes. According to the degasification theory the inoculant combines with gases dissolved in the iron to form solid inclusions which act as nuclei. By the silicate slime theory a submicroscopic "slime" of ferrous silicate is produced, the particles of which form nuclei for the formation of coarse graphite.

Some Aspects of Electric Melting in the Foundry. F. A. Rivett. (Institute of British Foundrymen: Foundry Trade Journal, 1945, vol. 77, Sept. 6, pp. 3-9). Brief descriptions are given of direct- and indirect-arc furnaces, resistor furnaces and high- and low-frequency induction furnaces. Their application for melting metals is discussed with details of power consumption, melting times and operating costs.

Annealing Malleable Iron. J. E. Rehder. (American Foundrymen's Association: Canadian Metals and Metallurgical Industries, 1945, vol. 8, June, pp. 29-34). The theory and practice of annealing white cast iron is discussed. The disadvantages of old standard practice taking 150-170 hr. are pointed out, and some short-cycle (24-30 hr.) annealing furnace installations are described. Some special processes (*e.g.*, quenching the white-iron casting in oil or water from above the critical temperature, and treatment of the molten metal with hydrogen) which reduce the annealing time still further are considered.

The Annealing of Whiteheart Malleable Iron by a Gaseous Process. A. G. Robiette. (Institute of British Foundrymen: Foundry Trade Journal, 1945, vol. 76, July 26, pp. 255-260; Aug. 2, 275-285; Aug. 9, pp. 305-310). See p. 81 A.

Production of Large Low-Alloy Steel Castings. J. R. D. Stapleton. (Institute of Australian Foundrymen: Australasian Engineer, 1945, vol. 44, July 7, pp. 33-37). A description, with numerous illustrations, is given of the moulding, pouring, cleaning and heat-treatment of a large low-alloy steel casting with the following overall dimensions: Length 17 ft. 7 in., width 6 ft. 8½ in., and depth 4 ft. 5 in.

Some Production Control Principles and Their Application to the Manufacture of Steel Castings. A. B. Lloyd. (Institute of Production Engineers: Foundry Trade Journal, 1945, vol. 76, Aug. 30, pp. 359-366). In the first part of this paper the basic conditions necessary in the organisation of a works to ensure that production control can be successfully applied are set out. A description of the principles of production control and their application to facilitate the production of steel castings is then given.

Statistical Control of the Manufacture of Steel Tank Shoes. A. E. R. Westman and R. W. S. Freeman. (Canadian Metals and Metallurgical Industries, 1945, vol. 8, June, pp. 38-43). The plant of Electric Steels, Ltd., near Three Rivers, Quebec, was originally designed for making cast-steel cases for 500-lb. bombs. In 1943 the manufacture of manganese-steel tank tread shoes was started. After some time the Ontario Research Foundation was asked to assist in reducing the percentage of rejects by applying methods of statistical control. A description of the manufacturing process and of the statistical methods applied is given, and the results achieved by it in ten months are discussed. These results were very beneficial, and fully justified the cost of introducing the control methods.

Steel Castings Radiography. E. L. La Grelus and C. W. Stephens. (American Foundrymen's Association : American Foundryman, 1945, vol. 7, July, pp. 46-56). Descriptions are given of the two one-million volt X-ray machines at the Granite City plant of American Steel Foundries. Many radiographs showing their application to improve the quality of steel castings are reproduced and discussed.

Control in the Gray Iron Foundry. A. J. Edgar. (American Foundrymen's Association : Foundry, 1945, vol. 73, July, pp. 88-89, 215-222). Examples of lack of control or faulty control at foundries leading to a high proportion of rejected castings are cited and methods of improvement are outlined.

"Photo Position Finding." A. C. Kalk. (American Foundryman, 1945, vol. 7, July, pp. 67-71). A technique by which a purchaser of castings can, when necessary, rapidly inform the supplier the position of any defect he may find on machining is described. The method is applicable when the quantities of similar castings justify the preparation of photographs from different angles and of sections at important positions. These photographs are made with a numbered scale across the top and a lettered scale down one side. The foundry and the purchaser have duplicate prints, and the position of a defect can be clearly specified by dropping perpendiculars from the position of the defect on the appropriate photograph to the two scales and quoting the number and letter at the points of intersection.

Carbon Products as Used in Various Metallurgical Applications. (Blast Furnace and Steel Plant, 1945, vol. 33, June, pp. 721-724). The advantages of using carbon for the following purposes are pointed out : (1) In the form of graphite rods in the risers of steel castings to lower the solidification temperature ; (2) as moulds capable of resisting extreme thermal shock ; (3) for coating moulds to prevent the metal sticking ; (4) in the form of bricks to line pickling tanks because it is inert to hydrofluoric acid ; and (5) to make crucibles for induction furnaces.

Initial Experience in Hydraulic Cleaning in a Steel Foundry Fetting Shop. F. N. Lloyd. (Institute of British Foundrymen : Foundry Trade Journal, 1945, vol. 76, Aug. 9, pp. 297-303 ; Aug. 16, pp. 319-324 ; Aug. 23, pp. 347-350, 346). See p. 82 A.

Molding Sand Properties at Elevated Temperatures. L. A. Kleber and H. W. Meyer. (American Foundrymen's Association : American Foundryman, 1945, vol. 7, July, pp. 26-30). An investigation of the hot-strength of Ottawa and Missouri moulding sands unbonded and bonded with different amounts of bentonite and cereal binder is reported.

PRODUCTION OF STEEL

(Continued from pp. 107 A-108 A)

United States Steel Industry. W. A. Hauck. (Iron and Coal Trades Review, 1945, vol. 151, Aug. 24, pp. 271-272). Complete details of the huge war expansion programme involving the steel and allied industries have been released by the United States War Production Board, and a summary of these is given in this article. Additional steel ingot and blast-furnace capacities amounted to 15.3 and 15.4 million tons per annum respectively. At January 1, 1945, the production capacities for steel ingots and pig iron were 95.5 and 67.3 million tons per annum respectively, and coke and sinter production had been increased by 13.4 and 11.5 million tons respectively.

Rebuilding the Soviet Iron and Steel Industry. V. V. Rikman. (Vestnik Akademii Nauk, U.S.S.R.: Iron and Coal Trades Review, 1945, vol. 151, Aug. 24, pp. 280, 288). The Institute of Metallurgy of the Academy of Sciences in the U.S.S.R. completely reorganised its plans for 1943 and 1944 for the rebuilding of the Soviet iron and steel industry. An outline of the problems involved and some of the methods of solving them is given. New plant and equipment are to be standardised as much as possible. Larger open-hearth furnaces (but not exceeding 180–200 tons) are to be built and more mechanical equipment to increase the production per man-hour is to be installed.

What Stream Conservation Means to the Iron and Steel Industry. J. R. Hoflert. (Iron and Steel Engineer, 1945, vol. 22, July, pp. 77–82). The pollution of streams by effluents from various industries and the legal aspect of water pollution in the United States are discussed. Types of industrial waste water and liquors and some methods of treating them are reviewed.

Process Control in the Production of Sulphur Steel. G. A. Ferris and H. Clark. (Iron and Steel Engineer, 1945, vol. 22, July, pp. 37–42). The development of a basic open-hearth practice to produce good low-carbon free-cutting steel is described. The charges consisted of equal proportions of scrap and pig-iron. A series of curves is presented, in each of which one particular factor is related to the surface quality of the billets produced. These curves indicate that: (1) The combined total of residual chromium, nickel, molybdenum, copper and tin should not exceed 0.30%; (2) copper in excess of 0.10% in combination with sulphur is very detrimental; (3) the lime/silica ratio should be about 3.5; (4) the optimum rate of reducing the carbon is about 0.20% per hr.; (5) about 15–20% of the total manganese required should be added to the steel in the ladle; (6) the minimum final manganese/sulphur ratio consistent with good surface quality is 12; (7) the optimum teeming temperature is 2790° F.; (8) the optimum ingot-mould temperature is 200–300° F.; (9) a scale of soaking periods related to the ingot temperature on charging the pit should be established and adhered to; (10) the importance of thoroughly soaking high-sulphur steel to a uniform temperature before rolling cannot be too strongly stressed.

Establishing Basic Open Hearth Practice for Optimum Chromium Practice. R. G. Waite. (American Institute of Mining and Metallurgical Engineers: Blast Furnace and Steel Plant, 1945, vol. 33, June, pp. 708–711). The development of a suitable open-hearth furnace practice to obtain the maximum possible recovery of chromium from the high proportion of chromium steel scrap in the charge is described. Additions of ferrochromium were also made when this material was available. The degree of deoxidation of the bath when the addition was made and the time elapsing between making the addition and tapping were important factors affecting the amount of chromium recovered.

Recent Results from Fluidity Tests in the Melting of Chromium-Molybdenum Steels with and without Nickel in Basic Arc and Open-Hearth Furnaces. W. Ruff. (Stahl und Eisen, 1943, vol. 63, June 3, pp. 438–442). The results of spiral fluidity tests over a period of seven months taken from 400 heats of nickel-bearing and nickel-free chromium-molybdenum steels in a 20-ton basic-lined arc furnace and from some open-hearth heats are presented and discussed. These tests indicated whether it was necessary to superheat the melt. When the steel had a low fluidity value, the mechanical properties, as indicated by the reduction in area in the tensile test and the impact strength, were considerably reduced. The addition of nickel increased the fluidity of the steel from both electric and open-hearth furnaces. Data and curves are presented relating the

spoon, tapping and pouring temperatures to the length of the spiral cast in the fluidity tests. This form of test is of great practical value in working the heats.

Operation of 4-Ton Openhearth. H. K. Work and W. R. Webb. (Iron Age, 1945, vol. 156, Aug. 2, pp. 42-47). A description of a 1-ton experimental open-hearth furnace built by the Jones and Laughlin Steel Corporation has already been given (*see* Journ. I. and S.I., 1939, No. II., p. 67 A). The design of the furnace has been altered and its capacity increased to 4 tons. Details of the altered furnace, the instruments and the melting procedure are given in the present paper.

Regulating the Valves of Open-Hearth Furnaces. W. Offenberg. (Stahl und Eisen, 1943, vol. 63, Mar. 31, pp. 257-259). The disadvantages of the older types of Forter, Simplex and Siemens reversing valves for open-hearth furnaces are discussed, and new designs for interconnected flue and gas-valves and flue and air-valves are described. One of these consists of a sloping-gate motor-driven valve in the flue, mechanically connected to a butterfly valve for reversing the air.

Surface Defects on Ingots and Billets. G. Helmer. (Iron and Steel Institute, 1945, Translation Series, No. 233). An English translation is presented of a paper which appeared in *Jernkontorets Annaler*, 1944, vol. 128, No. 9, pp. 457-503 (*see* Journ. I. and S.I., 1945, No. I., p. 48 A).

FORGING, STAMPING AND DRAWING

(Continued from p. 109 A)

The Design of Dies for One-Operation Forming. C. W. Hinman. (Steel Processing, 1945, vol. 31, June, pp. 373-378). A description is given of the dies used to form round steel tube, with a yoke along its side, from a flat sheet steel blank in one stroke of the press ram.

Forming Stainless Steel with Zinc Alloy Dies. W. W. Broughton. (Metals and Alloys, 1945, vol. 21, June, pp. 1626-1628). Improvements in the preparation of dies made of zinc alloys have increased their life. Some examples of dies, made of a zinc-copper-aluminium alloy, used for pressing stainless steel parts are described and illustrated.

Hydraulic-Press Stamping. G. W. Birdsall. (Steel, 1945, vol. 117, July 30, pp. 78-80, 122-124). Illustrated descriptions are given of some small self-contained hydraulic presses. The ram pressure can be controlled between 300 and 8000 lb./sq. in. Ram speeds between 20 and 200 in./min. with a length of stroke from $\frac{1}{2}$ in. up to 6 in. are obtainable.

Precision Bolts and Studs. (Automobile Engineer, 1945, vol. 35, Aug., pp. 313-322). A detailed account is given of the manufacture of high-quality bolts and studs at the works of A. P. Newall and Co., Ltd. The bolts and studs are made by cold-heading. The pickling, heat-treatment and thread-rolling processes, and the methods of control which ensure the high quality of the products are also described.

Determination of the Drawing Force in the Bright-Drawing of Steel. W. Lueg and A. Pomp. (Stahl und Eisen, 1943, vol. 63, May 13, pp. 373-380). *See* p. 9 A.

Increasing the Production of Rod-Drawing Shops by Multiple Drawing. F. Boehm. (Stahl und Eisen, 1943, vol. 63, June 30, pp. 469-476; July 15, pp. 495-497). The conversion of draw-benches from single-bar operation to multiple drawing for up to ten bars at a time is described. In the case of ten bars they are drawn in two vertical rows of five.

Reactive Wire Drawing. Part I. J. M. Howden and R. W. Lunt. (Wire Industry, 1945, vol. 12, Aug. pp. 411-415). In 1934, J. Dick

attempted to interpret the experimental observations of F. C. Thompson on the effect of backward pull upon the tension required to draw wire (*see* Journ. I. and S.I., 1933, No. II., pp. 369 and 374). In this mathematical treatise the authors extend and elaborate Dick's theory, showing how to calculate the length of wire drawn per unit of energy expended. They find that no significant economy in energy is to be expected by using "reactive" drawing—*i.e.*, drawing with a backward pull.

ROLLING-MILL PRACTICE

(Continued from pp. 110 A–111 A)

Determining Power Requirements when Rolling Similar and Dissimilar Sections. M. Steffes. (Stahl und Eisen, 1943, vol. 63, Apr. 15, pp. 295–301). An analysis is made of the current consumption at two rolling-mills, one producing heavy and medium sections and the other producing rounds from 5.0 to 12.7 mm. in dia. The effect of the reduction per pass and the production per hour is demonstrated by curves drawn from frequent "spot" readings of ammeters and revolution counters. Calculations are made showing the relationship between the electricity consumption and the total cost of production. The application of the data to the calibration of rolls and the selection of mill motors is discussed.

Relay Protection for Steel Plant Systems. C. L. Eichenberg. (Iron and Steel Engineer, 1945, vol. 22, July, pp. 46–50). A description is given of two two-wire A.C. pilot wire relay systems for protecting the power circuits at a steelworks; the purpose of the relays is to isolate faults by tripping the minimum number of circuit-breakers.

The Rectifier Installation at Alan Wood Steel Company. A. D. Howry. (Iron and Steel Engineer, 1945, vol. 22, July, pp. 62–68). The experience gained in the operation of the mercury-arc rectifier system at the rolling-mills of the Alan Wood Steel Co. is discussed. Greatly improved efficiency and a high degree of reliability have been achieved. The equipment has been described in an earlier paper (*see* Journ. I. and S.I., 1944, No. I., p. 15 A).

Applications of Electronics in Industry. L. T. Campey. (Mechanical Engineers' Association and the Institution of Production Engineers: Australasian Engineer, 1945, vol. 44, July 7, pp. 44–57). A large number of industrial applications of electronics are briefly described. These are classified in fifteen groups as follows: Power rectification and frequency conversion, adjustable-speed electronic drives, control of resistance welding, heating, temperature control, the "electric eye," inspection and testing, measurement, positioning control, speed matching and voltage control, electronic timing, lighting, X-rays in industry, electrostatic precipitation and carrier current.

Something New in Remote Control for the Steel Industry. T. J. Kaufeld. (Sheet Metal Industries, 1945, vol. 22, Aug., pp. 1356–1359, 1366). A brief description is given of the Yardeny-ATF remote control system which has been successfully used in military equipment; it is expected to have many applications in the steel industry. It is an electro-mechanical device by means of which an operator is able to control a motor-driven mechanism at a remote location in such a manner that the controlled unit will assume a desired location with extreme accuracy. An operator can, for example, control the rotation of a shaft connected to an electric motor and located out of sight and hearing, to any desired angle, within one or many revolutions with an accuracy of 0.01°.

Increasing the Production of a Heavy Plate Mill by Time-Study Methods. M. Reckziegel. (Stahl und Eisen, 1943, vol. 63, May 27, pp. 409-418). The increase in production and the other advantages obtainable by introducing the "unit production" system at a heavy plate mill are discussed. By this system the production of each of many sizes of plate per unit of time is calculated from time-study data. The quantity of one particular size produced in unit of time is selected as a basis to which the rates of production of the other sizes are related by a "sort factor." A formula for determining the ideal "sort factors" for different sizes is presented and it is shown how to trace the causes of differences between the actual and the ideal "sort factor." The advantages of the system are: (1) It can be applied to any mill and enables a fair comparison of rates of production to be made; (2) it shows which mill is most suitable for rolling a given specification; (3) it indicates what steps can be taken to increase production; and (4) it can be used with advantage in the drawing up of wages agreements in which wages are related to output.

Automatic Screwdown Control. A. F. Kenyon and W. G. Cook. (Steel, 1945, vol. 117, Aug. 13, pp. 124-128, 170-173). A description is given of the switching mechanism for controlling the roll setting in the 4-high roughing stand of the plate-mill at Geneva, Utah. The two pairs of rolls for this stand are 132 in. long and 38 in. and 56 in. in dia. respectively. The electric control is designed to move the screw-downs automatically to the preselected settings for each pass of the rolling schedule. The speed of the screwdown drive is reduced as it approaches the selected position so that it will stop exactly at the desired point.

Metallurgical Problems in the Manufacture of Seamless Gun Tubes. J. C. Carpenter. (Metal Progress, 1945, vol. 48, July, pp. 67-72, 112). A description is given of the development of the manufacture of 40-mm. and 75-mm. gun barrels from seamless steel tubes made by piercing steel billets. It is shown how the causes of defects were discovered and eliminated.

HEAT-TREATMENT

(Continued from pp. 111 A-113 A)

The Process and Equipment for Heat-Treatment with the Heat of Rolling. R. Schäfer and J. Fröhling. (Stahl und Eisen, 1943, vol. 63, Apr. 22, pp. 312-319). The heat-treatment of bars of carbon steel and of alloy steel utilising the residual heat after rolling is discussed and shown to be both practical and economical. The equipment for transporting and quenching the bars is described.

Annealing of Steel from the Rolling Heat. R. Schäfer and E. Langenbach. (Stahl und Eisen, 1943, vol. 63, May 20, pp. 399-402). It is shown that the structure of ball-bearing steel is improved by annealing from the heat of rolling. The structure of the granular pearlite thus obtained is more homogeneous than that obtained by the usual annealing procedure. When the proper rolling temperature is applied and the steel is air-cooled to slightly above the A_{r1} point with subsequent annealing, not only is a very good annealed structure obtained, but economic advantages are also achieved. This applies to many tool and heat-treatable steels. It is shown that the advantages of heat-treatment from the heat of rolling can be exploited to the full by planning the rolling programmes so as to anneal the material in batches.

High Carbon Steels. H. Shaw. (Iron and Steel, 1945, vol. 18, Aug., pp. 403-404). In the selection of an atmosphere for heat-treating high-

carbon steels particular care must be taken to prevent decarburisation. The advantages and disadvantages of cracked ammonia and of charcoal gas for this purpose are discussed with data on the capital outlay and operating costs of the two kinds of plant.

Heat Treatment Atmospheres, Generators and Furnaces. A. R. Wayman. (Australian Institute of Metals: Australasian Engineer, 1945, vol. 44, July 7, pp. 58-81). A comprehensive account is given of the production and application of furnace atmospheres for bright annealing and for gas-carburising.

Bearing Races Improved by Isothermal Treatment. J. P. Deringer. (Metal Progress, 1945, vol. 48, July, pp. 80-87). A detailed description is given of a continuous heat-treatment plant for hardening and tempering small ball races of 1%-carbon 1.5%-chromium steel. The plant consisted of a series of electrically heated salt-baths and quenching tanks through which the rings passed on a single conveyor. The heat-treatment consisted of: (1) Preheating at 1350° F. for 3½ min.; (2) heating at 1580° F. for 6½ min.; (3) quenching to 500° F. and holding for 2 min.; (4) cooling in air; and (5) tempering at 350° F. for 7½ min.

Tocco Hardening. H. B. Osborn, jun. (S.A.E. Journal, 1945, vol. 53, July, pp. 377-386, 391). The principles of induction heating are explained in simple language, and many of its applications to parts used in automobile manufacture are described and illustrated.

High-Frequency Induction Heating. W. M. Roberds. (Mechanical Engineering, 1945, vol. 67, July, pp. 448-451). The efficiency of heating by high-frequency induction is compared with that of heating by radiation and the advantages and limitations of the former method are discussed with special reference to the effect of different frequencies on the efficiency of energy transfer.

Magnetic Controls for Electric Furnaces. G. W. Heumann. (Metals and Alloys, 1945, vol. 21, June, pp. 1637-1642). Details are given of the instruments and circuits used to control electric reheating and heat-treatment furnaces by magnetic means.

Comparative Results Obtained through the Purnell Method of Heat Treating. C. G. Purnell and H. Pfahl. (Steel Processing, 1945, vol. 31, June, pp. 364-370). See p. 113 A.

Some Experiments in Nitriding. F. F. Dodson. (Machine Shop Magazine, 1945, vol. 6, July, pp. 84-88). Experiments are described the object of which was to ascertain whether defects in nitrided cases were caused by the steel being greasy or by the presence of an oxide skin. It was found that neither grease nor oxide prevented a good uniform case from being obtained. The presence of soft spots after nitriding is due to processing the material in a stagnant gas. The orthodox procedure is to keep the ammonia dissociation at approximately 30%, for which purpose the rate of gas flow is only 0.8 cu. ft./hr. This was found to leave soft spots. Processing loads of material with a gas rate of 3 cu. ft./hr. gave excellent results with uniform hardness and case depth. A successful but unorthodox procedure was developed which cut the total processing time of 35¼ hr. down to 27 hr. A very useful method of testing large batches of small components is to apply light shot-blasting, after which soft areas are shown up by a roughened surface.

Sub-Critical Annealing. E. E. Howe. (Iron Age, 1945, vol. 156, Aug. 9, pp. 52-55). Several examples are cited of the beneficial results obtained by annealing steel sheets before stamping as well as castings before machining, the treatment being for only 3 or 4 hr. at slightly below the critical point.

Spheroidizing Treatment. E. N. Simons. (Machinery, 1945, vol. 67, Aug. 23, pp. 210-213; Aug. 30, pp. 235-237). A concise explanation of

spheroidising is given, and the nature and purpose of the treatment are discussed with special reference to the treatments for steels for ball bearings and cold pressings. The advantages of this treatment are : (1) It puts the steel into the most machinable condition ; (2) when correctly carried out it lengthens the life of a tool steel ; (3) it improves the ability of the steel to be cold-worked ; and (4) it gives a better grain structure to the steel when finally hardened.

Effect of Prior Treatment on Results of Sub-Zero Process in Hardening High-Speed Steel. S. M. DePoy. (Production Data: Steel, 1945, vol. 117, July 16, pp. 122, 163). The effect of varying the position of the cold-treatment at -100°F. in the sequence of operations in the treatment of 4/5/4/1.7 chromium-tungsten-molybdenum-vanadium high-speed steel was investigated. The treatment which gave the greatest increase in the life of the tool consisted of: (1) Preheating to 1600°F. ; (2) hardening by quenching from 2225°F. in molten salt at 1050°F. ; (3) cooling in air to $100\text{--}150^{\circ}\text{F.}$; (4) tempering at 1050°F. for 2 hr.; (5) holding at -100°F. for 3 hr.; and tempering at 1050°F. for 2 hr.

An Appraisal of Subzero Hardening of High Speed Steel. J. G. Morrison. (Iron Age, 1945, vol. 156, July 26, pp. 54-60; Aug. 2, pp. 64-70). The results obtained by various heat-treatment cycles, all involving refrigeration treatment, on high-speed steel are critically reviewed. A very thin oxide coating on the threads of a high-speed steel tap increases its life because it reduces the tendency to seizure. As a tool comes up to room temperature after treatment at -100°F. , condensate may cause a fine oxide film to form and this may contribute to its increased life just as much as the cold treatment. The surface hardness of carburised, quenched and cold-treated high-speed steel responds to tempering in the same way as similar specimens without the cold-treatment. The change in dimensions of molybdenum and tungsten high-speed steels during heat-treatment with and without refrigeration are discussed.

Sub-Zero Treatment Improves Tool Life. (Machinist, 1945, vol. 89, Aug. 11, pp. 597-598). Details are given of a heat-treatment procedure which has extended the life of 18/4/1 high-speed steel tools used for making bolts and nuts. The treatment consists of: (1) Preheating to $800\text{--}850^{\circ}\text{C.}$; (2) hardening in oil from 1250°C. ; (3) tempering for $1\frac{1}{2}$ hr. at 565°C. ; (4) cold-treatment for 6 hr. at -120°F. ; and (5) tempering at $565\text{--}600^{\circ}\text{C.}$

Agitation for Effective Quenching Produces Uniform Results in Heat Treating. R. B. Seger. (Steel, 1945, vol. 117, July 23, pp. 110, 154). The necessity of providing for forced circulation of the cooling oil for quenching parts of large mass in order to obtain uniform hardness is stressed by citing the case of chromium-tungsten steel shear blades measuring $33 \times 6 \times 2$ in.

Continuous Drawing of A.P. Shot. C. A. Litzler. (Steel, 1945, vol. 117, July 30, pp. 100, 126). A brief description is given of a continuous furnace for tempering armour-piercing shells up to 3 in. in dia. The temperature is automatically maintained at within $\pm 3^{\circ}\text{F.}$ of the preset temperature and a rapid rate of heat transfer is obtained by turning the shells as they pass through the heating zone.

WELDING AND CUTTING

(Continued from p. 114 A)

Welding as an Aid in the Fabrication of Ordnance Material. S. B. Ritchie. (Welding Journal, 1945, vol. 24, July, pp. 629-634). Many

examples of the application of welding in the construction of light and heavy guns, tanks, bombs and small arms are described and illustrated.

The Restriction of E 6012 Electrodes. O. Blodgett. (Welding Journal, 1945, vol. 24, July, pp. 651-657). The elongation, tensile strength and hardness of welds made with American electrodes E6010 and E6012 are compared and discussed. Both of these electrodes are of 0.06%-carbon steel; the difference lies in the coating which gives to E6012 a faster cooling rate. American welding specifications restrict the use of this electrode and a plea is made to have the restrictions lifted.

1945 Specifications for Metallic Arc Welding Electrodes. O. T. Barnett. (Steel, 1945, vol. 117, Aug. 6, pp. 112-115). A joint committee of the American Welding Society and the American Society for Testing Materials has revised the specifications for iron and steel welding electrodes. A guide to the new specifications is presented.

Constitution of Weld Metal. W. Andrews. (Transactions of the Institute of Welding, 1945, vol. 8, Aug., pp. 119-132). An account is given of research work carried out while the author was on the staff of the Advisory Service on Welding, Ministry of Supply. The primary object of the work was to provide more data on the character of metallic arc weld metal. The report is divided into three sections, namely: (1) General chemical analysis of the weld metal of representative commercial electrodes; (2) detailed examination of selected weld deposits; and (3) examination of metallic arc weld deposits made by anhydrous fluxes. An important point arising from the work done under section (3) was that the cleanest weld metal of all those examined was that deposited in association with a flux based on calcium fluoride. As this material is almost entirely neglected as a flux for mild steel electrodes further research on its use in electrode coatings is recommended.

Thermal and Metallurgical Aspects of the Welding of Hot-Dip Galvanised Steel. E. F. Pellowe and F. F. Pollak. (Sheet Metal Industries, 1945, vol. 22, Aug., pp. 1423-1426). The theory and practice of the resistance welding of galvanised steel are discussed and the influence of the four variable factors current, mechanical pressure, time and electrode size on the quality of the weld are explained. Higher mechanical pressure than for steel to steel is required. The copper electrodes are attacked by the zinc and the electrode tips must be cleaned in a manner which does not change the area of the tip. Galvanised work should not be etched with phosphate or phosphoric acid preparations before welding as this leaves an insulating film of phosphate. With projection welding the projections should be made before galvanising. When the correct conditions have been determined 16-gauge galvanised strip can be successfully welded to $\frac{1}{8}$ -in. galvanised plate.

Repair of Steel Castings. (Foundry, 1945, vol. 73, July, pp. 92-93, 250-253). Recommendations drawn up by a committee of the Society of Automotive Engineers for the repair of steel castings by welding are presented.

Repair of Defective Gray-Iron Castings. S. H. Brams. (Iron Age, 1945, vol. 156, Aug. 9, pp. 74-75). The welding and brazing procedures recommended by the Society of Automotive Engineers and the United States Ordnance Departments for repairing grey iron castings are reviewed. (See "Repair of Castings" by L. A. Danse, p. 13 A).

Fatigue Strength of Fillet, Plug and Slot Welds in Ordinary Bridge Steel. (Welding Journal, 1945, vol. 24, July, pp. 378-S-400-S). This report was prepared by the Committee on Fatigue Testing (Structural) of the Welding Research Council of the Engineering Foundation. It describes the tension-fatigue testing of several sets of welded flat steel specimens so designed that the loads were transmitted from one component to the other through the shearing of fillet, plug or slot welds. The joints were designed

to represent those made between one end of a flat plate or channel tension member in a bridge or building and a gusset plate or a chord member.

The Impact Strength of Some Metallic Arc Weld Metal Deposits at Elevated Temperature. J. F. Eckel and R. J. Raudebaugh. (Welding Journal, 1945, vol. 24, July, pp. 372-S-377-S). An investigation of the impact strength at temperatures up to 1800° F. of welds in $\frac{3}{8}$ in. plate of 0.2% carbon steel is reported. Electrodes of low-carbon steel and 22/12 chromium-nickel steel were used. Welds made with carbon steel electrodes showed a marked reduction in impact strength with an increase in temperature from 600° to 1000° F. A very sharp rise in the impact strength occurred on raising the temperature above 1000° F. Specimens of stainless steel weld metal fractured completely at all testing temperatures up to 1800° F.; the impact strength increased steadily from room temperature up to 1600° F. and then fell somewhat at 1800° F.

Testing Welded Structures by the Tee-Bend Test. L. C. Bibber and J. Heuschkel. (Steel, 1945, vol. 117, July 16, pp. 124-126, 164-173). The T-bend weldability test introduced by the United States Navy Department has already been described (see Journ. I. and S.I., 1942, No. II., p. 67 A). In this paper a modification of the test involving energy measurement is described. A device is fitted to the bending machine which enables the loads and deflections to be read off as the bending proceeds. A load-deflection curve is constructed and the area under the curve is determined with a planimeter; this area represents the energy absorbed.

Gas Cutting of Stainless Aided by Fluxing System. (Iron Age, 1945, vol. 156, Aug. 9, p. 61). Stainless steel is rather difficult to cut by the oxy-acetylene process because of the oxides and the viscous slag which are formed. This difficulty has been overcome by injecting a flux in dry powder form into the oxygen line. A brief description of the injection equipment is given. The flux is inexpensive and about 1 oz. per min. is required when cutting stainless steel plates from 1 to 5 in. thick.

Method Is Developed for Flame Cutting Stainless Steel. (Steel, 1945, vol. 117, Aug. 13, pp. 107, 152). See preceding abstract.

PROPERTIES AND TESTS

(Continued from pp. 119 A-123 A)

The Technical Cohesive Strength of Some Steels and Light Alloys at Low Temperatures. D. J. McAdam, jun., R. W. Mebs and G. W. Geil. (Proceedings of the American Society for Testing Materials, 1944, vol. 44, pp. 593-623). A comprehensive report is presented on investigations of the technical cohesive strength of a high-carbon steel, a stainless steel, duralumin and magnesium alloys; it includes the results of tensile tests on notched and smooth specimens at room temperature and at selected low temperatures down to that of liquid air.

Non-Axial Loading of Gray Iron Tensile Specimens. J. O. Draffin and W. L. Collins. (Foundry, 1945, vol. 73, July, pp. 94-95, 180-182). The results of tensile tests and of strain measurements on eccentrically loaded specimens of grey cast iron are presented and discussed. These show that there is a substantial reduction in the tensile strength under eccentric loading. This reduction is affected by several conditions one of which is the plastic movement by which the iron adjusts itself to some extent to the eccentric load. Further research on this plastic movement is required.

A Quick Method of Calculating Elongation in Tensile Tests. M. S. Gerszonowicz. (Revue de Métallurgie, Mémoires, 1940, vol. 37, June, pp. 173-179). The author gives several formulæ applicable to the cal-

ulation of the elongation in tensile testing for cases where the normal procedure may prove to be unsatisfactory.

The Torsional Impact Strength of Tool Steel. R. Scherer and H. Kiessler. (Stahl und Eisen, 1943, vol. 63, May 6, pp. 353-357). The effect of tempering tool steels at up to 350° C. and high-speed steels at up to 650° C. on the torsional impact strength and toughness was investigated. It was found, in agreement with American test results, that the toughness increased at first with increasing tempering temperature; it then fell off and finally increased again. When tempered at the optimum temperature a 1%-carbon steel had the greatest impact strength; then followed, in order of decreasing toughness, a 1.5%-chromium ball-bearing steel, a 1%-chromium 1%-manganese 1%-tungsten steel (oil-hardened), a 1.1%-carbon 1%-tungsten steel, and a 2%-carbon 12%-chromium steel. The three tungsten high-speed steels tested had slightly lower impact strengths than the low-alloy tool steels. The torsional impact test described is recommended for comparing the toughness of very hard steels.

Metals for Service at Subzero Temperatures. P. B. Petty. (Chemical and Metallurgical Engineering, 1945, vol. 52, June, pp. 102-103). Data are presented on the impact strength of stainless steel, nickel, aluminium, copper and lead at temperatures down to -300° F. Increasing the nickel content of stainless steel up to 45% improves its impact strength at low temperatures.

A Transfer Strain Gage for Large Strains. M. Greenspan and L. R. Sweetman. (Journal of Research of the National Bureau of Standards, 1945, vol. 34, June, pp. 595-597). A simple strain gage, suitable for measuring strains of from -16% to +32% of a gage length of 1.5 in., is described.

The Electric Strain Gage. G. Brewer. (Metal Progress, 1945, vol. 48, July, pp. 91-96). A description is given of the Baldwin-Southwark electrical resistance strain gage. Its application to the stress analysis of various structures is discussed.

Characteristics of the Tuckerman Strain Gage. B. L. Wilson. (Proceedings of the American Society for Testing Materials, 1944, vol. 44, pp. 1017-1026). By means of an interferometric calibration device used at the National Bureau of Standards for calibrating gauges and autocollimators, experimental results were obtained which indicated the variations of the calibration factor under different conditions. The Tuckerman strain gage is described and the results of tests on the accuracy of the readings obtained with it are given. Recommendations are made on methods of attaching the gage to the structure to be tested.

The Measurement of Strain in Components of Complicated Form by Brittle Lacquer Coatings. W. J. Clenshaw. (Proceedings of the Institution of Mechanical Engineers, 1945, vol. 152, No. 2, pp. 221-223). The "Stress-coat" apparatus and the method of using it are described. Components of complicated shape can be sprayed with this lacquer and allowed to dry, and when the component is loaded in a testing machine the crack formations and crack spacings in the brittle coating indicate the approximate amount and the direction of the strain in the underlying material. The solvent for the lacquer is carbon bisulphide and the operator requires a gas mask which is supplied with the spraying equipment.

Strain-Age Embrittlement. W. E. Bardgett. (Sheet Metal Industries, 1945, vol. 22, Aug., pp. 1389-1397, 1417). Ageing is defined as a change in properties occurring gradually at atmospheric temperatures and more rapidly at higher temperatures; strain ageing is ageing following plastic strain. Means of measuring the embrittlement of strip (0.08-0.12%-carbon basic open-hearth rimming steel) too thin to provide a standard impact specimen were studied. None of the properties revealed by tensile,

hardness or bend tests can be used as a measure of the susceptibility to strain age embrittlement. The most promising method of detecting embrittlement of strip material resulting from straining and ageing is by means of miniature impact specimens. Tests results indicated that strip material is less susceptible to strain-age embrittlement than bar material—both materials being rolled from the same billet. There is no relation between the degree of ageing as measured by an increase in hardness and by a decrease in notched-bar impact value, *i.e.*, strain age hardening is not the same as strain age embrittlement.

Third Progress Report on the Effect of Size of Specimen on Fatigue Strength of Three Types of Steel. D. Morkovin and H. F. Moore. (Proceedings of the American Society for Testing Materials, 1944, vol. 44, pp. 137–155). The Second Progress Report dealt with the effect of size on the fatigue strength of notched and polished specimens (*see* Journ. I. and S.I., 1945, No. I., p. 86 A). In this Report the effect of residual stresses in machined and polished specimens of the same three kinds of steel (0.20% and 0.35% carbon steels and a chromium-molybdenum steel) is considered. Specimens thoroughly annealed after machining and polishing were tested in a rotating cantilever fatigue testing machine. The endurance limit decreased as the size of the specimens increased from $\frac{1}{8}$ in. in dia. to some value between $\frac{1}{2}$ in. and $\frac{3}{4}$ in. in dia. This was good evidence that the size effect persisted after the removal of any residual stresses.

A New Microhardness Tester and Examples of Its Application. R. Woxén. (Jernkontorets Annaler, 1945, vol. 129, No. 6, pp. 243–272). (In Swedish). A new hardness number, called the Woxén hardness number, is proposed. This number is the quotient of the test load divided by the area of the impression left by the diamond indenter below the original surface of the specimen. The relationships between the Woxén number H_w and the Brinell, Vickers and durometer numbers are calculated. It is shown that the quotient c of H_w divided by any of the other hardness numbers for a given material is a constant in the ideal case, and is related to the mechanical properties. The advantages and disadvantages of the static methods of measuring hardness are reviewed and a new microhardness tester for determining the Woxén number is described.

Factors Affecting Hardness Relationships in the Range 50 to 250 Brinell. R. H. Heyer. (Proceedings of the American Society for Testing Materials, 1944, vol. 44, pp. 1027–1045). Earlier work on the relation between Brinell, Vickers and Rockwell hardness values has been continued (*see* Journ. I. and S.I., 1943, No. II., p. 166 A). Data are presented which show the effect of the work-hardening capacity of the metal and of the duration of the load on the hardness value. A method, based on observation of the contour of the indentation, is described by means of which general hardness conversion tables of improved accuracy can be obtained.

Hardenability Band Data Set Up for 35 More Steels. (Steel, 1945, vol. 117, July 16, pp. 116–121). A joint committee of the Society of Automotive Engineers and the American Iron and Steel Institute have published curves for the maximum and minimum hardness (constructed from the results of Jominy end-quench tests) for three nickel steels, two chromium-nickel steels, five nickel-molybdenum steels and twenty-five N.E. steels. These curves and the analyses of the steels are reproduced.

Controlling Quality of Steel Castings. J. W. Juppenlatz. (Iron Age, 1945, vol. 156, July 19, pp. 50–54). Radiographic, fluorescent and Magnaflux methods of testing steel castings are reviewed and the lessons which can be drawn from the results of such tests are discussed.

On the Magnetic Structure of Iron. E. Lifshitz. (Journal of Physics, 1944, vol. 8, No. 6, pp. 337–346). The shape and dimensions of the domains of spontaneous magnetisation in iron crystals are determined.

Metallographic Identification of Ferro-Magnetic Phases. E. A. M. Harvey. (Metallurgia, 1945, vol. 32, June, pp. 71-72). A description is given of a simple apparatus for the positive identification of magnetic constituents in a non-magnetic matrix, or *vice versa*. The specimen is mounted in bakelite immediately above an electromagnet and its surface is covered with a magnetic colloidal suspension. On applying a magnetic field there is a visible concentration of the colloid over the magnetic areas.

Study of the Effect of Variables on the Creep Resistance of Steels. H. C. Cross and W. Simmons. (Proceedings of the American Society for Testing Materials, 1944, vol. 44, pp. 161-185). This paper constitutes the Third Progress Report on research at the Battelle Memorial Institute on factors affecting the creep resistance of steel (for the Second Progress Report, see Journ. I. and S.I., 1941, No. I., p. 222 A). The results of creep tests at 850° F. on a silicon-killed steel, a silicon-aluminium-killed steel, an aluminium-killed non-ageing steel, a molybdenum rimming steel and on weld metal of carbon steel and of molybdenum steel are reported and discussed. Heat-treatments producing various austenite and ferrite grain sizes did not affect the creep-resistance of a 0.14%-carbon silicon-killed steel. Coarsening the grain of a 0.17%-carbon silicon-aluminium-killed steel improved the creep resistance. Air-cooling after coarsening did not produce a good creep resistance in an aluminium-killed non-ageing steel, but quenching in water produced a very low rate of creep. Plain carbon and carbon-molybdenum steel weld metal both had better creep resistance than wrought steel of the same composition heat-treated to the optimum creep-resistance.

Creep-Resistant Alloy Steels. S. E. Wolfson and M. P. Myahkov. (Iron Age, 1945, vol. 156, Aug. 2, pp. 58-63). An English translation is presented of a paper from the Russian journal *Stal*, 1943, No. 3-4, pp. 42-47. The results of tensile and creep tests at temperatures up to 600° C. on the following alloy steels are presented: (1) Silicon steels; (2) chromium-molybdenum steels; (3) chromium-nickel-molybdenum steels; (4) chromium-manganese-silicon-molybdenum steels; (5) chromium-vanadium steels; and (6) chromium-molybdenum-vanadium steels.

Austenitic Manganese Steel. L. Sanderson. (Canadian Mining Journal, 1945, vol. 66, July, pp. 471-474). The properties of austenitic manganese steel are discussed. In addition to the usual mechanical properties the following special properties of 1.0-1.3%-carbon 12-14%-manganese steel are given: Melting point 1343° C., electrical resistance 70.0 (copper 1.7241), thermal conductivity 2.31 (copper 100), specific heat at room temperature 0.145, and coefficient of expansion 0.00001 per degree F. The effect of small additions of nickel and the reasons for using nickel-manganese steel welding rods for the repair of manganese steel castings are given.

Titanium in Chrome-Manganese Stainless Steel. G. F. Comstock. (Iron Age, 1945, vol. 156, Aug. 9, pp. 62-66). The effects of titanium additions on the properties of 12%-chromium 17%-manganese austenitic steel was investigated. Even as little as 0.14% of titanium increased the yield strength of the steel in the quenched and tempered state by 15-20%. With 0.75% of titanium a greater increase in the yield strength was obtained with very little loss of ductility and resistance to impact. With 1.6-3.0% of titanium hardness values of about Rockwell C40 and C60, respectively, were obtained by temper hardening, but these steels were either unforgeable or had a very low impact resistance.

Role of Molybdenum and Associated Alloys in Cast Iron. J. C. Kinsella. (American Foundrymen's Association: Canadian Metals and Metallurgical Industries, 1945, vol. 8, June, pp. 35-37, 57). The effects of molybdenum, chromium, copper and vanadium on the properties of cast iron are discussed.

Effects of Boron in Steel. R. B. Corbett and A. J. Williams. (United States Bureau of Mines, June, 1945, Report of Investigations No. 3816). Extensive laboratory investigations on the effects of boron additions to steel are reported. Over 100 induction-furnace heats were prepared, and sixteen different addition agents were used. The more important conclusions reached were: (1) Boron may be used to produce fine-grained steels of good forging characteristics; (2) a number of good addition agents are available; both "pyrobor" (dehydrated borax) and fused boron-trioxide glass, which are inexpensive, appear to be suitable sources of boron for steel; (3) the hardenability of steel increases with increasing amounts of boron up to 0.003% of boron, at which value the hardenability is 1.58 times that of the steel without the addition; further additions cause the hardenability to decrease; (4) the effect of 0.003% of boron on the hardenability of steel is equivalent to that of 0.87% of silicon, 0.79% of nickel, 0.27% of chromium, 0.12% of manganese, or 0.23% of molybdenum; (5) properties other than hardenability must be conferred by elements other than boron; (6) to ensure a good recovery boron should be added to a thoroughly killed steel; (7) to ensure good distribution the addition agent should be put in the ladle in several portions as it fills, and before the slag starts to flow over it; and (8) boron is most valuable in medium-carbon steels. A rapid and accurate colorimetric method for determining boron in steel is described.

Foreign Tool Steel Comparison Chart. (Iron Age, 1945, vol. 156, Aug. 2, pp. 48-50). Charts are presented which show the makers' names, brands, colour markings and analyses of British and Continental tool steels.

Cast Iron—Applications in the Chemical and Process Industries. F. L. LaQue. (Gray Iron Founders' Society: Iron and Steel, 1945, vol. 18, Aug., pp. 375-378). The usefulness of cast iron in the manufacture of plant which has to resist the attack of chemicals is discussed with particular reference to the high corrosion and scaling resistance of some of the alloy cast irons.

Strong, Light Iron Castings. W. M. Albrecht. (Metals and Alloys, 1945, vol. 21, June, pp. 1631-1636). The properties of "Z-Metal" are discussed and several examples of light and strong castings made of it are described. Z-metal is a cast iron made by adding manganese and copper to a white iron and applying a special heat-treatment consisting of annealing at 1600-1700° F. for 48 hr., cooling in air and reheating to 1250-1350° F. for 15-30 hr.

NE Steels for Bearings and Bolts in Farm Equipment. J. H. Clark, J. D. Walker and A. S. Jameson. (Metal Progress, 1945, vol. 48, July, pp. 97-104). In order to economise in alloying elements not readily available in the United States, the manufacturers of farm equipment resorted to National Emergency steels for many of their components. In this paper the use of these steels for making roller bearings and bolts is described, with particulars of the hardness and tensile strength obtained by heat-treatment.

Methods of Increasing the Strength of Reinforcing Bars after Rolling. B. D. Enlund and G. Sehlberg. (Jernkontorets Annaler, 1945, vol. 129, No. 7, pp. 297-314). (In Swedish). An account is given of an investigation of the increase in strength obtained by three forms of cold-work applied to concrete reinforcing bars of basic open-hearth, electric-furnace and basic-Bessemer low-carbon steel in bars 10, 16, 24 and 32 mm. in dia. The forms of cold-work were: (1) Extension by pulling the bars to produce permanent elongations of 10%, 15% and 20%; (2) drawing through dies to give reductions in cross-section of 10%, 15% and 20%; and (3) twisting 5-m. lengths by one complete turn per length of eight times the diameter.

The results are given in numerous tables, and comparisons are made of the stress-strain curves obtained.

High-Strength Reinforcing-Bar Steel. R. Wijkander and O. Knös. (*Jernkontorets Annaler*, 1945, vol. 129, No. 7, pp. 315-334). (In Swedish). The standard specifications of the European countries and the United States for reinforcing bars for concrete are reviewed and compared and means of improving the properties by cold-work or changes in composition are discussed. Methods of increasing the bond between the steel and the concrete are also considered. A bibliography with 40 references is appended.

The Good Behaviour of Low-Alloy Steels in Motor Lorry Construction. H. Balster and W. Eilender. (*Stahl und Eisen*, 1943, vol. 63, Mar. 31, pp. 249-257; Apr. 8, pp. 276-279). An extensive investigation of the application of low-alloy steels for highly stressed parts in motor-lorry engines is reported. Normalising from high temperatures increases the wear resistance. Hardening in 8% caustic soda solution has several advantages, in that no soft spots occur and even unalloyed carbon steels can be used for many stressed parts. For oil-hardening, a mineral oil at 40-50° C. with a viscosity of 2.5-3 Engler units should be used. Steels to various German engineering standard specifications are recommended for gears, crankshafts and connecting rods.

The Effect of Chemical Surface Treatments on the Scuffing of Gears. H. D. Mansion. (*Institution of Automobile Engineers: Engineering*, 1945, vol. 160, Aug. 10, pp. 117-118; Aug. 24, pp. 157-158; Aug. 31, pp. 179-180). An account is given of an investigation of the extent to which chemical surface treatments extended the life of gear teeth. Various phosphate treatments, a caustic-soda/sulphur treatment and tinplating were tried. Phosphate treatments appeared to be most effective in inhibiting scuffing; of these, manganese phosphate, which formed a comparatively deep and coarse-grained coating, provided the greatest protection. The results of further tests indicated that none of the surface treatments increased the tendency to failure by tooth breakage.

The Role of the Straight Chromium Stainless Steels for Vessel Linings in the Refinery Field. W. J. Jackel. (*Corrosion*, 1945, vol. 1, June, pp. 83-94). The ability of straight chromium steels to provide adequate protection against the corrosion of pressure vessels in oil refineries is discussed. The 12%-chromium steel has gradually replaced the 17%-chromium quality because the latter tends to become brittle in the 750-950° F. temperature range. An addition of 0.25% of aluminium to the 12%-chromium steel reduces its air-hardening tendency.

Non-Rusting Steels. A. M. Samarin. (*Iron and Steel*, 1945, vol. 18, July, pp. 226-229). This is an English translation of a paper which appeared in the *Bulletin de l'Académie des Sciences de l'U.R.S.S.* The effect of nitrogen on the mechanical properties of heat-treated stainless steels containing 17-20% of chromium and 5-9% of nickel was investigated. The austenite contents of the steels were determined after quenching, after reheating for 2 hr. at 650° C., and after reheating and boiling in Hatfield's reagent for 72 hr. The yield point and the ultimate strength of steels were increased by the reheating and boiling treatment. The stability of the austenite increased the more austenite there was present. Increasing the nitrogen content raised the tensile strength of the steels. The resistance of the steels to intercrystalline corrosion could be determined from measurements of the electrical resistance.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 95 A-97 A)

A Steel Foundry Laboratory. (Engineer, 1945, vol. 180, Sept. 7, pp. 183-184). An illustrated description is given of the modern laboratory at the works of K. and L. Steelfounders, Ltd., Letchworth. The laboratory building includes separate rooms for metallography, pyrometry, heat-treatment, X-ray work, sand testing, physical tests and chemical analyses.

Foundry Research at the Naval Research Laboratory. W. G. Gude. (Foundry, 1945, vol. 73, July, pp. 84-87, 167-171, 174). A brief survey is presented of the equipment and research work at the United States Naval Research Laboratory at Anacostia near Washington, where many investigations on steel-foundry practice are carried out.

The Radiometallographic Laboratory of L'École Centrale des Arts et Manufactures. L. Guillet and P. Bastien. (Revue de Métallurgie, Mémoires, 1940, vol. 37, June, pp. 161-172). A detailed and illustrated description is presented of the X-ray laboratory at L'École Centrale des Arts et Manufactures, Paris, preceded by a short review of various X-rays applications in metallurgy. Three groups of apparatus and their accessories are installed in the laboratory; these are intended for: (1) The examination of crystalline substances by the diffraction of X-rays, (2) the examination of these substances by electron diffraction, and (3) the detection of internal defects in metal components.

Photography for Research. S. H. Thorpe. (Iron and Steel, 1945, vol. 18, July, pp. 219-225, 240). Many applications of photography in the steel industry are described, and particulars are given of some new methods. One of these is to overcome the difficulty of photographing a large area of a prepared surface on steel at a reasonably high magnification. It is done by making the negative at a low initial magnification using a "maximum resolution" plate with an almost grainless emulsion; the final magnification is obtained by projecting the negative image.

Fractography—A New Tool for Metallurgical Research. C. A. Zapffe and M. Clogg, jun. (Steel, 1945, vol. 116, May 28, pp. 106-109, 148-154). See Journ. I. and S.I., 1945, No. I., p. 63 A.

The Primary Etching of Steel to Develop the Segregation Structure. K. Amberg and A. Hultgren. (Jernkontorets Annaler, 1945, vol. 129, No. 6, pp. 293-295). (In Swedish). A description is given of a method of preparing specimens and an etching procedure which shows segregation in ingots with good contrast. The method was developed at the works of A/B. Bofors, and is based on etching alternately with Stead's and Rosenhain & Haughton's solutions.

Study of Internal Stress in a Metal by X-Ray Diffraction. W. A. Wood. (Proceedings of the Institution of Mechanical Engineers, 1945, vol. 152, No. 2, pp. 232-234). The theory and practice of the measurement of internal stress in metals by X-ray diffraction are concisely explained. Only the stresses in the elastic range are considered. It is shown how to calculate the direction and magnitude of the principal stresses. The determinations are accurate within 1-2 tons/sq. in.

An X-Ray Study of Iron-Rich Iron-Silicon Alloys. Margaret C. M. Farquhar, H. Lipson and Adrienne R. Weill. (Iron and Steel Institute, 1945, this Journal, Section I). Although work on the iron-silicon system has been done in the past, there are still several problems connected with it that need solution. The present paper describes some experimental work, by X-ray diffraction methods, on the iron-rich part of the system. This work has confirmed the main outlines of the α phase boundary found

by previous workers, but has placed it on a firmer foundation by the use of data from more alloys. At temperatures between 1030° and 1195° C. the phase boundary has been modified by the discovery of a new phase, α'' , which calls for some modification of the equilibrium diagram. The reaction by which α'' is formed is unusual, and is discussed in some detail; by consideration of free-energy principles it is concluded that the reaction is either polymorphic or peritectic, but not peritectoid.

An interesting relationship has also been found between the orientations of the η phase and the α matrix in which it is precipitated; on the basis of this a reason is advanced for the precipitation of η outside its range of stability. The precipitation of η instead of ϵ has been observed particularly in commercial alloys.

CORROSION OF IRON AND STEEL

(Continued from pp. 123 A-124 A)

Protection of Iron and Steel. U. R. Evans. (Metal Industry, 1945, vol. 67, Aug. 24, pp. 114-117). The use of non-ferrous metals to protect iron and steel from corrosion is discussed. Coatings of metals cathodic to steel (copper and nickel) may be forced up in nodules at discontinuities by "under-rusting" under conditions of atmospheric corrosion, whilst under conditions of total immersion they may sometimes (but not always) intensify attack at gaps. Coatings of anodic metals (zinc and aluminium) avoid these troubles, but, as they are slowly "sacrificed" in providing protection to exposed steel, the choice of the metal appropriate to the environment requires to be made with discretion. Polarity itself depends on circumstances; zinc may become cathodic to iron in water at high temperatures, so that in galvanized hot water systems continuity of the coating is more important than in cold water systems. Of methods of coating which can be applied in the field, metal-spraying with aluminium from a wire pistol followed by an ordinary paint has proved valuable under exacting conditions. Another procedure is that of coating with a paint so richly pigmented with zinc as to constitute practically a galvanized coat; in certain circumstances, such coats make contact with the steel through the rust, which is partly reduced to metal, thus providing conducting bridges, but it is still not certain whether this will occur under all conditions. In laboratory tests, such paints applied to rusty steel have given cathodic protection in sea water to the metal exposed at scratch lines piercing the coat for periods of over two years. It must not be assumed too readily that such a coating will be suitable for all environments, but there is some hope that it will prove valuable in combating corrosion fatigue.

Corrosion Research and Abatement Yesterday and Today. F. N. Speller. (Corrosion, 1945, vol. 1, Mar., pp. 1-13). Research work on corrosion problems is reviewed and the organisation of the research in the United States is discussed.

Analysis of Data in Cathodic Protection of an Open Condenser Box. J. J. Stadtherr. (Corrosion, 1945, vol. 1, June, pp. 70-82). The results achieved in the application of cathodic protection to an open-top condenser box at an oil refinery are presented and discussed. The condenser box was 47 ft. 6 in. long \times 34 ft. 6 in. wide \times 10 ft. 6 in. deep. It was made of $\frac{1}{4}$ -in. steel plate and angles, and contained 255 4-in. cast-iron pipes. Experience showed that cathodic protection is a valuable supplement to other methods of protection employed by oil refineries. With careful distri-

bution of anodes of suitable shape (such as iron plates or grids suspended between vertical rows of tubes) the protection achieved justifies the expenditure. To obtain the best results it is necessary that certain areas have "over-protection," as this ensures that more remote areas receive some degree of protection.

Economies of Mitigation of External Corrosion on Underground Pipe Lines. J. C. Stirling. (Corrosion, 1945, vol. 1, Mar., pp. 17-30). Instances of the corrosion of buried steel pipe-lines carrying petroleum products for long distances in Texas and other parts of the United States are cited. Inspection after several years service proves that the cost of protection by wrapping, and of cathodic protection, is more than repaid by the increased life obtained. Another economic factor is that with adequate protection the thickness of the pipe walls can be reduced.

Progress Report on the Behaviour of Zinc-Iron Couples in Soils. M. Romanoff. (Corrosion, 1945, vol. 1, June, pp. 95-102). In order to study the effectiveness of zinc for the cathodic protection of iron and steel under various soil conditions, zinc-iron couples were buried at eight test sites by the National Bureau of Standards in 1941. The galvanic currents produced by the couples and the potentials of the separate elements were measured as often as possible under war-time conditions. The couples have been removed from two of the sites, and a report on their condition and behaviour as indicated by the electrical measurements is made.

Electrical Resistivity of Steel. R. P. Howell. (Corrosion, 1945, vol. 1, Mar., pp. 14-16). A table and a graph are presented which show the electrical resistivities of a large number of steels, especially those used for high-strength steel pipe-lines.

Marine Tests Rate Alloy Performance. J. Albin. (Iron Age, 1945, vol. 156, July 26, pp. 62-67, 82). A description is given of investigations in progress at the corrosion testing station at Kure Beach, Wilmington, where tests are being conducted by the co-operation of the Dow Chemical Company, the Carnegie-Illinois Steel Corporation and the International Nickel Company, Incorporated. Prolonged tests under and above the sea-water on panels of low-alloy and high-alloy steel, plated steel and non-ferrous metals and alloys are being made.

Future Metals Are Given "Test Runs" at Cape Fear, N.C. I. H. Such. (Steel, 1945, vol. 117, Aug. 13, pp. 110-113, 158-160). An illustrated description is given of the marine-corrosion testing station at Kure Beach, near Cape Fear, where 15,000 ferrous and non-ferrous test panels are at present exposed to the action of salt-laden air, and to sea-water. Some of the results obtained are briefly reviewed. (See preceding abstract).

The Interpretation of Visual Rusting Standards. W. F. Singleton. (Proceedings of the American Society for Testing Materials, 1944, vol. 44, pp. 910-915). An example is given of the determination of the degree of rusting of steel tank plates by comparison with the A.S.T.M. photographic rusting standards for painted steel.

The Salt-Spray Corrosion Test. G. T. Dunkley. (Mechanical World, 1945, vol. 118, Aug. 17, pp. 179-181, 192-195). The applicability of the salt-spray corrosion test for the following purposes is discussed: (1) Testing the porosity of cathodic coatings; (2) checking the thickness of anodic coatings; (3) estimating the life of a coating; (4) testing oxide and phosphate coatings; (5) examining paint and lacquer films; (6) determining the tendency of copper-zinc alloys to dezincification; (7) examining the behaviour of two metals coupled together; (8) developing new alloys; and (9) testing zinc-base die-castings for their susceptibility to intercrystalline corrosion. The urgent need for a standardised salt-spray test is pointed out.

Basic Requirements in the Standardization of the Salt Spray Corrosion Test. L. J. Waldron. (Proceedings of the American Society for Testing

Materials, 1944, vol. 44, pp. 654-662). The increased use of the salt-spray test has made it advisable to revise the many conflicting test specifications and to produce a standard method of testing. The variables affecting the data obtained are discussed in the light of recent experiences with the test.

ANALYSIS

(Continued from pp. 99 A-101 A)

Determination of Nitrogen in Steel and Steel Welds. R. H. Powell. (Welding, 1945, vol. 13, July, pp. 249-252). The formation of stable metallic nitrides in steel and steel welds is discussed and methods of determining the nitrogen content of welds are described with special reference to the apparatus designed by H. Kempf and A. Abresch (*see* Journ. I. and S.I., 1940, No. II., p. 77 A).

The Application of Potentiometric Volumetric Analysis in the Iron Works Laboratory. VI. The Determination of Sulphur in Iron, Steel, Ferro-Alloys, Slags and Ores. G. Thanheiser and P. Dickens. (Iron and Steel Institute, 1945, Translation Series, No. 236). An English translation is presented of a paper which appeared in *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1933, vol. 15, No. 19, pp. 255-262 (*see* Journ. I. and S.I., 1934, No. I., p. 629).

A Spot Test for Molybdenum in Steel. W. H. Hammond. (Iron Age, 1945, vol. 155, June 28, pp. 75-76, 138). A description is given of a rapid test, requiring very little equipment, for detecting molybdenum in alloy steels. The test is based on obtaining a red precipitate of molybdenum cinchonine thiocyanate.

A Method for Determining Low Carbon Contents in Steel. G. Ericsson. (Iron and Steel Institute, 1945, Translation Series, No. 232). An English translation is presented of a paper which appeared in *Jernkontorets Annaler*, 1944, vol. 128, No. 11, pp. 579-596 (*see* Journ. I. and S.I., 1945, No. I., p. 116 A).

Colorimetric Determination of Copper in Iron and Steel by the Diethyl-Dithiocarbamate Method. A. Thomas. (Proceedings of the American Society for Testing Materials, 1944, vol. 44, pp. 769-770).

Colorimetric Determination of Titanium in Chromium Alloyed Steels, Using a Klett-Summerson Photo-Electric Colorimeter with Filter No. 42. (Proceedings of the American Society for Testing Materials, 1944, vol. 44, pp. 771-772).

Colorimetric Determination of Phosphorus as Molybdivanadophosphoric Acid. M. G. Mellon. (Proceedings of the American Society for Testing Materials, 1944, vol. 44, pp. 772-773).

Colorimetric Determination of Molybdenum in Alloy Steels. E. R. Vance. (Proceedings of the American Society for Testing Materials, 1944, vol. 44, pp. 773-774).

Determination of Phosphorus, Manganese, Molybdenum and Titanium in Stainless Steels by Glass Color Filter Photometry. W. J. Boyer. (Proceedings of the American Society for Testing Materials, 1944, vol. 44, pp. 774-778).

The Spectrochemical Determination of Metallic Impurities in Steel. C. G. Carlsson. (*Jernkontorets Annaler*, 1945, vol. 129, No. 5, pp. 193-241). (In Swedish). An examination has been made of spectrochemical methods of analysing steel samples in solid form as well as solutions of steel in either nitric or hydrochloric acid. The main object was to determine the elements manganese, chromium, nickel, molybdenum, cobalt,

vanadium, titanium, copper, tin and aluminium when present in the 0.1–0.001% range. The method of evaporating a little of the solution to dryness on a carbon electrode was tried using one of the three following sources of light: (a) The continuous D.C. arc; (b) the interrupted D.C. arc as described by Pfeilsticker; and (c) the high-voltage A.C. arc as described by Duffendack and his collaborators. Method (b) proved to be the most suitable as a basis for a standard method. This method was found to give a standard deviation of ± 4 –7% for most elements. Methods (a) and (b) were tried for the analysis of solid samples, but the formation of molten oxide on the electrode tips was found to lower the accuracy of the analysis; the best result, a standard deviation of ± 4 –7%, was obtained with the interrupted arc when the arc was allowed to burn only for a short interval each time it was struck, thus preventing too high a temperature at the tips of the electrodes.

The spectrochemical methods are more accurate and more sensitive than the chemical methods for determining very small percentages of most elements; chemically analysed standard samples cannot therefore be used if the possibilities of the spectrochemical methods are to be fully exploited. When solutions are used for the spectrographic analysis, accurate standard samples may be obtained without resorting to chemical analysis by mixing pure solutions of the different elements; the solution method was therefore developed and taken as a basis for other methods. An attempt was also made to prepare standard alloys of known composition by melting together the constituents, and these alloys were checked by the solution method with satisfactory results. Some steel samples which had been carefully analysed by chemical means were analysed spectrographically using metallic electrodes as well as solutions; the results were in good agreement. Fairly high amounts of alloying elements in the steel do not seem to influence the results of the trace analysis when the solution method is used, but, with metallic electrodes, such an influence was found in some cases. Most metallic elements may be determined by the methods described when present in concentrations down to 0.001–0.002%. The accuracy is in most cases ± 0.001 % for amounts less than 0.020%, and ± 0.005 % for amounts of about 0.1%. The solution method may be used with advantage in microanalysis. Quantitative determinations can be carried out with a total sample weight of a few hundredths of a gramme. A bibliography with 70 references is appended.

Bibliography of Photoelectric Spectrophotometric Methods of Analysis for Inorganic Ions. J. W. Stillman. (Proceedings of the American Society for Testing Materials, 1944, vol. 44, pp. 740–748). This bibliography is made up of references to papers in volumes 1 to 16 of the Analytical Edition of "Industrial and Engineering Chemistry" in volumes 62 to 69 of "The Analyst." The references are classified under the various elements in alphabetical order.

BOOK NOTICES

(Continued from pp. 124 A–126 A)

BENYON, C. E. "*The Physical Structure of Alloys.*" 8vo, pp. 126. Illustrated. London, 1945: Edward Arnold and Co. (Price 6s. 6d.)

This volume offers a concise and systematic introduction to modern theory concerning the physical structure of alloys. Gathered together here, and related to one another, the achievements of the metallurgical physicists during the last two decades impress the reader with the magnitude of the change that has come over our knowledge of the inner structure of metals. The author starts by con-

sidering the modern conception of the structure of the atom in relation to the periodic table of the elements, and follows this up with the theory of electronic valency and atomic structure of crystals, the various methods of X-ray examination of crystalline solids being shortly but clearly described. Following this, the space lattices found in metal crystals are dealt with, and, engaged as the author now is on a study in three dimensions, he departs from the study of the atom for a little to give a brief but adequate explanation of crystallographic notation.

The fundamentals having been given, we now see how these have been applied to explain many of the seeming anomalies and irrelevancies of alloy systems. The work of W. Hume-Rothery and his co-workers on the atomic structure of solid solutions and intermetallic compounds is given full prominence in the three following chapters, and the author shows how strong is the evidence linking our knowledge of the atom with the properties and structures of alloys. In the final chapter there is a brief survey of modern physical theory as applied to metals, in which the "metallic" properties of electrical and thermal conductivity are explained in terms of atomic structure, and the concentration limits of solid-solution phases are shown to be in accordance with the attainment of a theoretically determined electron concentration in various alloys. Mr. Benyon writes lucidly and enthusiastically on his subject. His avoidance of any but the simplest of mathematics and the adequacy of the illustrations make his work accessible to all those with a grounding in what we may now perhaps call "classical" metallography, and will enable such persons to assimilate in connected form the results of modern research in this subject.

S. L. ROBERTON.

Institute of Economic Engineering. "*Time-Study and Rate-Fixing.*"

Edited by The Institute of Economic Engineering. This publication is based on Lectures given by F. L. Meyenberg from May to September 1943. 8vo, pp. xxi + 225. Illustrated. London, 1945: The Engineers' Digest and Sir Isaac Pitman and Sons, Ltd. (Price 20s.)

This book, based on lectures by Prof. Meyenberg, has resulted in a publication which will in all probability become a textbook for all engineers whose special responsibility is tied to production economy in engineering works, and in particular to those who are practically employed in setting fair and equitable standards of performance for an operation or process.

Prof. Meyenberg cannot be considered a newcomer to the ranks of the ever-increasing contributors to literature on engineering economics, and in some respects this book dilates on principles incorporated in a book published in 1938 entitled "The New Management," of which he was a joint author.

"*Time-Study and Rate-Fixing*" is divided into five sections: (1) The Analysis of Time; (2) Rate-Fixing; (3) The Carrying Out of Time Studies; (4) The Application of the Results of Time-Study for Determining Working Times; and (5) Grinding. A concluding chapter deals with the education of the time-study engineer and his position in relation to the works organisation.

The sequence chosen has the advantage of enabling the student to obtain progressive understanding of the basic principles of manufacturing economy. His knowledge is the ideal foundation for any system having as its object economic production for the entrepreneur, and satisfactory wage returns for the worker. That the attainment of this very desirable result involves the determination of a whole host of factors from many different aspects should generally be understood amongst production engineers; even so, however, the present-day tendency to specialist manufacturing organisations precludes the opportunity for many rate fixers to broaden their experience of those manufacturing processes that offer considerable variation between types of product. Careful study of this book can in many ways help to overcome that deficiency. Its examples of manufacturing methods, both turning and grinding, are numerous and are chosen to cover a broad and varied field of application.

One very satisfactory feature that is brought to the reader's attention is the warning that time-study is not just the application of a hard and fast set of rules, tables and formulae which can rigorously be applied to any manufacturing organisation or process; on the contrary, emphasis is placed on the need to rate-fix with due respect to the particular circumstances of the process or factory unit in question. In the section devoted to time, the importance of this element is discussed and its relationship to main and supplementary operations on typical manufacturing processes is illustrated by many examples taken from actual practice. These examples and the manner in which they are presented to the reader serve to stimulate interest in methodical planning, and above all develop the attitude of viewing the job objectively in relation to the time factors involved in its manufacture.

In the discourse on time-study technique, the practical side is covered by notes on the varying types of stopwatch to be used to suit particular circumstances, together with different methods for recording the time-study data. The importance of rating the effort and skill of the worker under observation is stressed, but, in contradistinction to many publications on the subject of time-study, the rating method recommended is largely based on the observer's practical experience and not on theoretical calculations or laboratory experiments. The references to the proper assessment of the conditions under which work is carried out, together with the need to make a careful analysis of the demands made on the operator according to the nature and characteristics of a particular job, are an important feature, and methods of using this information to fix basic wage rates are shown with examples.

The sections dealing with time-study and rate-fixing applied chiefly to turning and grinding are comprehensive in the treatment of established machine- and grinding-shop technique. It must not, however, be assumed from this statement that these sections merely comprise sets of figures and formulæ which can be found in any standard machinists' or engineers' pocket-book. In this treatise the author has reinforced the known formulæ of established practice with observed data obtained by experience in a great variety of circumstances. This has resulted in numerous examples of charts, tables and diagrams linking machine-tool to method. The advantages to be obtained from the preparation of charts, particularly the time saved in tedious calculation by the rate-fixing department of a manufacturing organisation, will readily be apparent from a study of the book, and the rate-fixing student will find plenty to inspire him.

It is a pity that automatic time-recording devices have not received more attention, if only because of their labour-saving propensities in war-time and other periods of labour shortage. The Pieseler Diagnostiker, it is felt, would have been an example instrument worthy of mention, in particular, the application of such a machine to production grinding on machines of the Heald type. The question of rota shift-working and its consequent increase in machine utilisation would also have made a further contribution to the general overall value of the book; particularly as a means of placing on record the methods adopted during the war for solving the problem of labour shortage by the employment of married women with domestic responsibilities.

G. L. POTTER.

PATERSON, D. G. P., and BEARN, J. "*An Outline of Industrial Metallurgy.*" 8vo, pp. viii + 185. Illustrated. London, 1944. Chapman and Hall, Ltd. (Price 12s. 6d.)

In their preface the authors state that this volume is based on a series of articles entitled "The Training of the Young Metallurgist" which appeared in "Sheet Metal Industries" during 1942 and 1943. The expansion of these articles under the more comprehensive title of their book has not eliminated all traces of their origin, and the reader frequently encounters a treatment of the subject which, although acceptable in an article in a technical journal, is out of place in a textbook, even of the introductory type. The whole book suffers from a marked lack of arrangement, extending from the chapter headings to the illustrations, and much of the value of the authors' information on any subject is lost by its being disseminated through a number of parts of the book. The first chapter on "The Scientific Basis of Temperature Measurement," starts with a short general statement regarding the training and functions of a metallurgist, and goes on to deal shortly with the theoretical bases of pyrometry, with descriptions and illustrations of the instruments used for temperature measurement. We encounter the subject again in Chapter X, headed "Heat Treatment of Aluminium Alloys and Stainless Steels. Pyrometric Equipment," where are given additional illustrations and descriptions, but with reiteration of some of the information included in the earlier chapter. Many other examples of this haphazard arrangement could be quoted.

It is unfortunate that this salient defect should be present, for the authors' text is often concise, and always informative, but in the course of reading more than a few pages one becomes aware of the repeated necessity for reorienting one's mind to an unexpected change in subject unconnected with what goes before or after, except *via* the wide scope implied by the title of the book.

That the authors have endeavoured to fulfil the terms of reference imposed by their choice of title is evident from a survey of the subjects dealt with. These include the principles of smelting, mechanical properties of metals, metallurgical microscopy, heat-treatment, pyrometry, surface treatments, corrosion, and the joining of metals. One feels that a narrower field treated in a more systematic manner would have given the authors a better medium for passing on to the reader their very evident knowledge of their subject.

S. L. ROBERTON.

MINERAL RESOURCES

(Continued from p. 103 A)

Geology of a Middle Devonian Cannel Coal from Spitsbergen. T. Vogt. (Norsk Geologisk Tidsskrift, 1941, vol. 21, No. 1, pp. 1-12).

Petrology of a Middle Devonian Cannel Coal from Spitsbergen. G. Horn. (Norsk Geologisk Tidsskrift, 1941, vol. 21, No. 1, pp. 13-18).

Studies of the "Phosphorus Anomalies" of the Low-Phosphorus Iron Ores of Central Sweden. G. T. Lindroth. (Jernkontorets Annaler, 1945, vol. 129, No. 6, pp. 273-292). (In Swedish). The author discusses the phenomenon of the non-uniformity of the phosphorus content of some of the iron ores of Central Sweden. In some cases there is a sudden increase in the phosphorus with increasing depth of the ore bed.

Nevada Tungsten Ore Gets Three-Way Treatment. (Engineering and Mining Journal, 1945, vol. 146, July, pp. 81-85). An account is given of the geology of the scheelite deposits in Pershing County, Nevada, as well as of the mining operations and the concentration processes.

FUEL

(Continued from pp. 129 A-130 A)

Theoretical Quantities of Air and Flue Gases with Gaseous Fuels. H. A. Lundberg. (Iron and Steel Institute, 1945, Translation Series, No. 249). An English translation is presented of a paper which appeared in Jernkontorets Annaler, 1944, vol. 128, No. 12, pp. 617-620 (see Journ. I. and S.I., 1945, No. I., p. 144 A).

The Carburetting of Coke Oven Gas for Melting in Siemens-Martin Furnaces with Special Reference to the Use of Coal Tar Pitch. P. Bremer. (Iron and Steel Institute, 1945, Translation Series, No. 245). An English translation is presented of a paper which appeared in Stahl und Eisen, 1938, vol. 58, Dec. 1, pp. 1365-1369 (see Journ. I. and S.I., 1939, No. I., p. 141 A).

The Carburetting of Coke Oven Gas with Liquid Coal Tar Pitch and Supplementary Pitch Firing when Melting in Siemens-Martin Furnaces. Parts I. and II. P. Bremer and C. Meier-Cortes. (Iron and Steel Institute, 1945, Translation Series, No. 246). An English translation is presented of a paper which appeared in Stahl und Eisen, 1942, vol. 62, Oct. 29, pp. 913-920 (see Journ. I. and S.I., 1943, No. I., p. 118 A).

The Use of Blast-Furnace Gas. C. Monteil. (Revue de Métallurgie, Mémoires, 1941, vol. 38, Feb., pp. 33-42; Mar., pp. 57-72). Particulars are given of the cleaning, distribution and utilization of blast-furnace gas at iron and steel works. After describing briefly the characteristics of blast-furnace gas, the author deals in detail with its application for heating the blast and for gas engines. Constructional data and costs are given of gas-engine-driven electric power stations, and a comparison is made between gas engines and steam turbines.

The Economics of Gas and Steam Drives for the Production of Electricity in Iron and Steel Works. M. Steffes. (Stahl und Eisen, 1943, vol. 63, Aug. 12, pp. 573-579). The cost of producing electricity in iron and steel works is subjected to a careful analysis. To do this, separate accounts for capital, fuel and maintenance are set out and related to the nominal production, the degree of activity and the load. A method of presenting

costs which can be applied to a wide variety of plant conditions for either gas engines or steam turbines is shown. This demonstrates that gas engines are preferable for units up to 7500 kW. and that turbines are advantageous for larger units.

The Effect of the Degree of Activity on the Blast-Furnace-Gas Economy in Iron and Steel Works. M. Steffes. (Stahl und Eisen, 1943, vol. 63, Oct. 14, pp. 741-746). The relation between the degree of activity (*i.e.*, the ratio of actual production at a given time to the full productive capacity) of an iron and steel works and the production and consumption of blast-furnace gas is studied and diagrams are constructed showing this relationship in three types of works, namely: (a) merchant blast-furnaces; (b) a partially integrated iron and steel works, where 20% of the pig-iron requirements are purchased from other producers; and (c) a fully integrated iron and steel works.

The Becker Coke-Oven Plants in Douchy (Nord) and Waleswood (Yorkshire) Mines. C. Berthelot. (Revue de Métallurgie, Mémoires, 1941, vol. 38, Apr., pp. 89-97). Illustrated descriptions are given of the coke-oven plant at Douchy, which includes two batteries, one of 40 and one of 37 Becker ovens producing 810 tons of coke per day, and that of Waleswood comprising 23 Becker ovens with a daily production of 267 tons. Both installations represent typical examples of modern coke-oven plants, where efficient organization, mechanization and the use of control apparatus enables the best possible results to be obtained.

New Characteristics of the Physico-Mechanical Properties of Coke. L. M. Sapozhnikov and K. I. Syskov. (Iron and Steel Institute, 1945, Translation Series, No. 239). This is an English translation of a paper which appeared in Koks i Khimiya, 1940, No. 8, pp. 3-8. The mechanical properties of blast-furnace coke are evaluated by measuring the work performed in breaking down lumps of different sizes. The results obtained on a number of Russian cokes are cited and related to their performance in the blast-furnace.

Proposals for the Efficient Design, Equipment and Operation of Gas Producers, Especially for Open-Hearth Furnaces when Gasifying Rhine-Westphalian Coals. Part I. G. Neumann. (Iron and Steel Institute, 1945, Translation Series, No. 241). An English translation is presented of a paper which appeared in Archiv für das Eisenhüttenwesen, 1942, vol. 16, Dec., pp. 201-214. (See Journ. I. and S.I., 1943, No. I., p. 151 A).

Proposals for the Efficient Design, Equipment and Operation of Gas Producers, Especially for Open-Hearth Furnaces when Gasifying Rhine-Westphalian Coals. Part II. G. Neumann. (Iron and Steel Institute, 1945, Translation Series, No. 242). An English translation is presented of a paper which appeared in Archiv für das Eisenhüttenwesen, 1943, vol. 16, Jan., pp. 237-246). (See Journ. I. and S.I., 1944, No. II., p. 34 A).

Modern Metallurgical Gas Producers. C. Berthelot. (Revue de Métallurgie, Mémoires, 1941, vol. 38, Aug., pp. 207-221). The author reviews the present state of the development and use of gas producers in metallurgical and other industries, and presents operating data. A description is given of a modern gas producer installed at a steelworks and its thermal balance is calculated. The arrangement and the mechanization of a gas-producer plant and the acceptance tests are then considered. The recent improvements in gas-producer design enable fuels of inferior quality to be used successfully.

PRODUCTION OF IRON

(Continued from pp. 130 A-132 A)

The Development of Swedish Iron Production and Its Future Prospects. H. Åselius. (*Jernkontorets Annaler*, 1945, vol. 129, No. 8, pp. 345-376). (In Swedish). The history of the production of pig-iron and steel in Sweden from 1900 to the present time is reviewed and discussed, and numerous graphs are presented showing the fluctuations in the annual and daily production, the production of different types of furnaces, the fuel consumption, and changes in wages. The production data for Sweden are compared with those for other countries.

Russian Reconstruction.—Blast Furnace in Mariupol Resumes Production. I. Andronov. (*Iron and Steel*, 1945, vol. 18, Sept., p. 425). The restoration of four blast-furnaces at Mariupol on the coast of the Azov Sea, which were completely wrecked during the war, is briefly described.

The Pig-Iron Casting Machine Type GHH. R. Hahn. (*Stahl und Eisen*, 1943, vol. 63, Aug. 26, pp. 617-619). A description is given of the construction and operation of a pig-casting machine designed by Gutehoffnungshütte, Oberhausen, which can deal with 1200 tons of pig-iron in 24 hr. The machine has two strands 45 m. long, each carrying 300 chills. The two motors driving the strands require about 12 kW. each, and the life of the chills is about 180 casts. The machine requires a foreman and five men to operate it, and no heavy manual labour is necessary.

New Experience in the Operation of Blast-Furnace Stoves. W. A. Güldner. (*Stahl und Eisen*, 1943, vol. 63, Sept. 2, pp. 633-640). The fact that the gas consumption of a particular stove per ton of coke consumed in the blast-furnace remained practically unchanged when the blast temperature was lowered considerably led to an investigation of the plant conditions, a detailed account of which is presented. The results showed that the heat stored by the stove and the stove operation must be regulated so as to meet the fluctuating thermal requirements; measurement of the dome and flue-gas temperatures is insufficient for this purpose. It was found that by fitting a thermocouple at the end of the hot-blast main just before the junction with the cold-blast pipe and plotting the readings in conjunction with the blast temperature after mixing, excellent stove control could be achieved and troubles could be easily detected. An example of this is described. Using a short-flame burner and having a well-insulated hot-blast main reduced the gas consumption by 20-25%. A good unit for expressing the efficiency of stove operation is the figure obtained by dividing the blast temperature after mixing by the gas consumed in the stove per ton of coke burned.

Major Repairs to a Blast Furnace Stove. R. V. Huffman. (*Blast Furnace and Coke Association of the Chicago District: Blast Furnace and Steel Plant*, 1945, vol. 33, July, pp. 838-842). *See next abstract.*

Procedure for Making Major Repairs to Hot Blast Stove. R. V. Huffman. (*Steel*, 1945, vol. 117, Aug. 27, pp. 124-129). A description is given of the manner in which a blast-furnace stove was repaired, in particular, how the checkers were supported and the brickwork renewed where necessary without having to dismantle and completely rebuild the checkerwork.

Turbo-Blowers or Gas-Engine-Driven Blowers for Supplying Blast-Furnace Blast. F. Thönnessen. (*Stahl und Eisen*, 1943, vol. 63, Aug. 26, pp. 609-616). Developments in the designs of steam turbines and gas engines are discussed and the economic aspects of their application for driving blast-furnace blowers are considered. The development of

turbines has made very great strides in the last 20 years, and such a rate of advancement is not likely to be maintained. New methods of constructing gas engines enable their space and material requirements and the capital expenditure to be reduced. As far as these three factors are concerned the turbo-blower is superior to the gas engine, whilst maintenance costs are about the same for each. The gas engine consumes much more lubricating oil than the turbine of equivalent horsepower. On the other hand, the turbine plant requires many times more cooling and make-up water than the gas engine.

Atmospheric Moisture and Melting in Metallurgical Furnaces. A. Denison Williams. (*Revue de Métallurgie, Mémoires*, 1941, vol. 38, May, pp. 113-121). The moisture content in the air supplied to the blast-furnace affects its output and the consumption of fuel to a great extent. An exact knowledge of working conditions in the blast-furnace, as well as of blast temperatures, makes it possible to fix the range of humidity corresponding to the best results obtainable, and to guarantee these results within very close limits. In this connection the author gives an account of investigations made on 186 blast-furnace casts in Ohio, and describes the air-conditioning installation at Woodward, Alabama.

Method of Producing Low Carbon Pig Iron. A. D. Williams. (*Blast Furnace and Steel Plant*, 1945, vol. 33, July, pp. 849-851). A new design of blast-furnace hearth is suggested in which the stock and fuel are directed in front of the tuyeres and supported while the molten iron is drained into a "decanter" crucible. Contact between the fuel carbon and the iron is thus reduced, resulting in a pig-iron low in carbon the use of which in the open-hearth furnace would considerably reduce the refining time. An experiment produced a mixture of slag and iron, the carbon content of the latter being less than 2%. It is also claimed that the productivity of the circular blast-furnace would be increased.

Gas Flow and Coke Consumption in the Blast Furnace. K. Neustaetter. (*Blast Furnace and Coke Association of the Chicago District: Steel*, 1945, vol. 117, Aug. 20, pp. 153-157, 184; *Blast Furnace and Steel Plant*, 1945, vol. 33, July, pp. 825-829). Experience gained concerning the effects of coke size, drying the blast and charging bushy turnings on blast-furnace operation at the works of the Inland Steel Company are discussed. It was possible to charge one-third of the coke as small as $\frac{5}{8}$ in. with a reduction of only 15% in the volume of blast per minute by making sure that different sizes were not charged simultaneously. A test was made with a furnace working on dried blast by increasing the blowing rate so as to replace the weight of oxygen removed in the moisture by an equal amount of oxygen in the form of air (*i.e.*, 3.86 lb. of air for every 1 lb. of moisture); the furnace took an increased burden, but violent kicking developed and the blast rate had to be reduced to a lower level than before.

Powder Metallurgy Production of Machine Parts. (*Machinery*, 1945, vol. 67, Sept. 27, pp. 337-343). The manufacture, by the powder-metallurgy process, of a wide variety of parts used in motor-car production is described.

Particle Size Analysis of Iron Powders in Powder Metallurgy. H. H. Steinour. (*Iron Age*, 1945, vol. 155, May 17, pp. 65-71). Methods of making an analysis of the particle size of iron powders are described and a comparison is made of analyses of five commercial iron powders using the Wagner turbidimeter. This apparatus was developed for Portland cement analyses, and the method consists in following the course of sedimentation of a dilute suspension of the powder in liquid by taking measurements of the turbidity, using a light of constant intensity, a photo-electric cell, and a microammeter connected across the cell.

FOUNDRY PRACTICE

(Continued from pp. 132 A-134 A)

Malleablizing Iron Castings. J. Fallon. (Foundry Trade Journal, 1945, vol. 77, Sept. 20, pp. 53-56). A description is given of the Lee Wilson furnace for malleablizing iron castings, and of the heating and cooling system employed. These furnaces are heated with gas-fired radiant tubes and are constructed in various sizes, but in all cases the charge is loaded on a platform and the furnace is lowered over it. The furnace is gas-tight, and some of the carbon in the castings combines with the oxygen in the initial atmospheres to form carbon monoxide which prevents scale from forming on the castings. The charge is heated to 900-950° C. and held for 20-25 hr.; it is then cooled rapidly to 760° C. by lifting the furnace and blowing air through the load; the furnace is replaced until the temperature has become uniform and decreased slowly to 700° C., after which it is raised and the castings are cooled in air. A very low fuel consumption in relation to the load is reported.

High Tensile Steel for Castings. W. West, C. C. Hodgson and H. O. Waring. (Institute of British Foundrymen: Foundry Trade Journal, 1945, vol. 77, Sept. 20, pp. 47-52; Sept. 27, pp. 69-76, 80; Oct. 4, pp. 101-104). Methods of improving the quality of high-tensile steel castings at a foundry using two basic-lined arc furnaces are described. To eliminate "hydrogen flakes" the procedure of boiling down to 0.1% of carbon before slagging was adopted; the burnt lime, even if somewhat hydrated, had no adverse effect when used for making the second slag. A large ladle addition of aluminium to basic electric steel helped to produce a fine grain size and to increase the toughness. A modification of the Schofield-Grace thermocouple very suitable for the steel foundry is described. An investigation showed that the presence of marked columnar primary crystals had no effect on the Izod impact value of some castings made to test this. The effect of various heat-treatments on the mechanical properties of low-chromium 1%-manganese cast steels is discussed and test data are presented. Finally, the properties of suitable moulding and core sands are dealt with.

Thermit Casting Technique. R. T. Brown. (Steel, 1945, vol. 117, Sept. 3, pp. 134-137, 188-190). A technique for producing steel castings by the thermit process is described.

The Bonding Action of Clays. Part I. Clays in Green Molding Sand. R. E. Grim and F. L. Cuthbert. (Illinois University, 1945, Engineering Experiment Station Bulletin Series No. 357). This is a report on an investigation conducted by the University of Illinois and the State Geological Survey in co-operation with the Illinois Clay Products Company. A basis for the classification of bonding clays is provided by the mineral components of the clays because the properties are largely determined by them. Such a classification is presented, and the properties of four groups—namely, the montmorillonite, halloysite, illite and kaolinite bonding clays—are described and discussed.

Sand Problems in the Casting of Steel. S. H. Ljunggren. (Jernkontorets Annaler, 1945, vol. 129, No. 8, pp. 457-517). (In Swedish). After setting out the requirements of a good steel-foundry sand, the state of sand research in the United States, England, Germany and Sweden is discussed. The occurrence and properties of suitable sands and clays in Sweden are examined. The temperatures at the surface of a test mould wall were measured, and the contact zone between steel and sand was subjected to a mineralogical study under the microscope. The buckling

and scabbing tendency decreased very markedly with increasing strength of the medium-coarse sands investigated. Buckling appeared to be caused by the increase in volume of the quartz grains, especially by the sudden increase of 2.4% at the transformation (575° C.). The steel should be poured so rapidly that the mould face has not time to reach 575° C. before the steel is in contact with it. The adherence of sand to the casting increases with increasing permeability of the sand; thus, the scabbing tendency can be reduced by increasing the proportion of fine sand.

Sand Reclamation. R. Webster and A. C. Den Breejen. (*American Foundryman*, 1945, vol. 8, Aug., pp. 49-57). The advantages and disadvantages of the wet system of reclaiming used foundry sand are discussed, and data on the properties of new and reclaimed core sands from steel and grey iron foundries and a magnesium foundry are presented.

Graphite Molds for Short-Run Castings. J. Putchinski. (*Iron Age*, 1945, vol. 156, Sept. 6, pp. 83-85; 170-174). The use of graphite inserts to line centrifugal casting machines is discussed. Graphite rods are easily bored out to the requisite size for casting bushes, and their life is adequate where the number of castings required is not very great. Even when worn they can be rebored to make a mould for a larger bush.

Equipment Trends in Precision Casting. A. J. Dore. (*American Foundryman*, 1945, vol. 8, Aug., pp. 65-71). Descriptions are given of the equipment used for making small precision castings by the "lost wax" process.

Gamma-Ray Radiography. R. A. Gezelius. (*American Foundryman*, 1945, vol. 8, Aug., pp. 30-32). The advantages and disadvantages of using gamma-ray radiography for the detection of faults in castings are discussed.

PRODUCTION OF STEEL

(Continued from pp. 134 A-136 A)

Material Flow Diagrams for an Integrated Iron and Steel Works. H. W. Benschmidt. (*Stahl und Eisen*, 1943, vol. 63, July 29, pp. 529-537; Aug. 5, pp. 558-567). Sankey diagrams illustrating the flow of materials in an integrated iron and steel works producing 650,000 tons of basic-Bessemer steel and 350,000 tons of open-hearth steel per annum are constructed. Separate diagrams for the blast-furnaces, Bessemer shop, open-hearth and rolling-mill are reproduced. The obtaining of the necessary data, the drawing-up of material balances and the construction of the diagrams are discussed. Finally, a diagram showing the flow of iron per annum through the whole works is presented and the important facts which are brought into prominence by these diagrams are considered.

Furnace Design. A. H. Leckie. (Swansea and District Metallurgical Society, Mar., 1945). Open-hearth furnace design with particular reference to gas flow and combustion is discussed, the subject being dealt with in four sections: (1) General principles governing satisfactory flow conditions; (2) determination of the size of passages by calculation of pressure losses; (3) the upper part of the furnace—melting chamber and ports; and (4) other features of furnace design.

Operation of an Experimental Open-Hearth Furnace. H. K. Work and W. R. Webb. (*Steel*, 1945, vol. 117, Sept 3, pp. 138-142, 192-196). See p. 136 A.

Notes on Basic Open Hearth Plant and Practice. J. McKay and W. G. Cameron. (*Journal of the West of Scotland Iron and Steel Institute*, 1944-45, vol. 52, Part II., pp. 19-38). A detailed description is given of the plant and practice at the melting shop of the Lanarkshire Steel Com-

pany, Ltd. At its present stage of development the furnace bay holds three 90-ton and five 70-ton fixed basic open-hearth furnaces; these operate on the cold-metal/scrap process and are fired with raw producer gas.

Some Fundamental Problems in the Manufacture of Steel by the Acid Open-Hearth Process. G. R. Fitterer. (Campbell Memorial Lecture: Transactions of the American Society for Metals, 1935, vol. 34, pp. 41-70). Recent developments in American acid open-hearth practice are reviewed and the furnace reactions are considered in detail. An entirely new ternary diagram is constructed by combining the Bowen and Schairer diagram of the binary system FeO-SiO_2 with that of Conley and Royer for the system MnO-SiO_2 . It is shown that as the temperature of an acid open-hearth heat increases, the SiO_2 content of the slag increases whereas its FeO content decreases, and that the MnO content of the slag remains essentially constant throughout the heat in American practice. As a slag-fluidity test can be used as a rapid means of determining the SiO_2 content, and as the MnO content of the slag for a given charging practice is known, these two factors can be plotted on the new $\text{SiO}_2\text{-MnO-FeO}$ diagram to give the third factor, *i.e.*, the FeO content, and this in turn permits a rapid estimation of the slag temperature to be made. Proportions of the relative diagrams and curves, enlarged to a convenient scale, are reproduced, and it is shown how the furnace personnel can use these in conjunction with the slag-fluidity test to control acid open-hearth heats. Data are presented showing that a considerable amount of metal is in suspension in the slag during the active refining period, and this is oxidized by the reduction of ferric oxide which is continually being formed in the slag by the action of the furnace gases; this confirms the theory of J. H. Whiteley and A. F. Hallimond (*see* Journ. I. and S.I., 1919, No. I., pp. 223-240).

Western Steel Plant Obtains 178 Heats from Electric Furnace Roof. E. G. Jones. (Steel, 1945, vol. 117, Sept. 10, pp. 124-130). A description is given of the construction of the silica brick roof of a 40-ton basic electric furnace 15 ft. in dia. The newly lined roof is preheated for 60 hr. before the first heat. After the first heat is tapped, the accumulated dust is blown off the roof and a thin mixture of sillimanite cement is poured over the brickwork and swept into the joints.

Electric Furnace Construction and Operation. Part I. Construction and Maintenance of Electric Arc Furnaces. J. C. Howard and G. L. Willan. (Journal of the West of Scotland Iron and Steel Institute, 1944-45, vol. 52, Part I., pp. 1-6). A comprehensive account is given of the construction and maintenance of electric arc furnaces. Improvements in charging methods, rotating hearths, switch gear including air-blast high-tension switches, transformers, electrode regulators and methods of preparing monolithic dolomite linings are described.

Electric Furnace Construction and Operation. Part II. Some Notes on Basic Electric Arc Furnace Practice. J. M. Mowat and J. A. Anderson. (Journal of the West of Scotland Iron and Steel Institute, 1944-45, vol. 52, Part I., pp. 7-16). War-time experience in the operation of three 15-18-ton basic electric-arc furnaces is related. The silica brick roofs were made of 9-in. crowns, and a strip of felt was placed on each ring and between each second brick radial; this gave an average roof life of thirty charges. This practice was changed to that of inserting a $\frac{1}{4}$ -in. wood expansion piece at every fourth brick radial, and this increased the life to forty-eight charges. Improvements to the electrode cooling rings are also described. On an average, over 80% of the electrical power consumed is used up in melting down, and more research on the optimum voltage and amperage for melting and refining is recommended. Particulars of two typical charges are presented and discussed.

The Effect of Non-Metallic Inclusions in Case-Hardening Steels from the Basic Electric-Arc Furnace. E. Maurer and R. Schustek. (Stahl und Eisen, 1943, vol. 63, Oct. 7, pp. 725-731; Oct. 14, pp. 747-751). An investigation of the factors affecting the occurrence of non-metallic inclusions leading to hair-line cracks in rolled billets of a 1%-manganese, 1%-chromium, 0.2%-molybdenum steel made in a basic-lined arc furnace is reported. Sections from the top, middle, and bottom of the billets were examined under the microscope, with the naked eye and by the magnetic powder process. The effects of the rolling temperature, degree of deformation, top- and bottom-pouring, casting temperature and speed, and various deoxidizing agents were studied. The best ratings, judged by microscopic examination, were obtained by steel treated in the ladle with calcium silicide and aluminium, and this was independent of the type of refining slag and the casting temperature. Judged by macroscopic methods the cleanest steel was produced by killing with calcium-aluminium and calcium-manganese-silicon, and casting at 1440-1460° C. at a rate of 0.43 tons/min.

REHEATING FURNACES

(Continued from pp. 108 A-109 A)

Heating Furnaces in New Oldsmobile Forge Plant of Modern Design and High Capacity. (Industrial Heating, 1945, vol. 12, June, pp. 928-944). An illustrated description is given of the furnaces and machinery in the forge shop at one of the works of the General Motors Corporation, where modern steam hammers ranging from 3000-lb. to 15,000-lb. units have been erected.

Time-Temperature Relationships in Workpieces. V. Paschkis. (Mechanical Engineering, 1945, vol. 67, July, pp. 445-447-452). Data on the rate of heating steel bars and slabs in reheating furnaces and the factors affecting this rate are discussed.

Developments in Rotary Hearth Furnaces. J. H. Loux. (Iron and Steel Engineer, 1945, vol. 22, July, pp. 52-59). Descriptions are given of modern rotary-hearth furnaces for reheating and for heat-treatment, special reference being made to the charging and discharging equipment.

The Control of Furnaces with Semi-Gas Firing. K. Guthmann. (Stahl und Eisen, 1943, vol. 63, Sept. 9, pp. 659-663). Economic methods of controlling semi-gas-fired furnaces are described and discussed. These furnaces burn a solid fuel with insufficient primary air, and secondary air is supplied to burn the hydrocarbon gases above the fuel bed. Both air supplies should be controlled for economic operation.

FORGING, STAMPING, AND DRAWING

(Continued from pp. 136 A-137 A)

Forging Die Design. J. Mueller. (Steel Processing, 1945, vol. 31, July, pp. 438-439, 454). Recommendations are made on the design of dies for large, fairly flat, thin forgings.

Automotive Crankshafts Forged on Mechanical Presses. (Iron Age, 1945, vol. 155, Feb. 22, pp. 62-64). A description is given of the forging of automobile engine crankshafts in large high-speed forging presses. In some cases only three blows were required instead of the twelve to fifteen necessary with a steam hammer.

Automotive Bolts. A. S. Jameson. (Iron Age, 1945, vol. 156, Aug. 23, pp. 64-69; Aug. 30, pp. 47-49). The properties of steels suitable for making bolts by cold-heading and hot-heading are discussed.

The Economic Utilization of Labour in Wire-Drawing Shops. E. Jaenichen. (Stahl und Eisen, 1943, vol. 63, Sept. 16, pp. 669-673).

ROLLING-MILL PRACTICE

(Continued from pp. 137 A-138 A)

The Further Development of Rolling Mills. A. Nöll. (Stahl und Eisen, 1943, vol. 63, Apr. 29, pp. 332-337). The technical and commercial considerations affecting the selection and design of rolling-mill stands are discussed and the merits of two-high and three-high stands are compared, the former being recommended for rolling bars to close tolerances. Recommendations on the lay-out of mills for rolling medium and light bars and wire are made.

Mill Built for Russia Can Roll Billets, Strip, Rounds or Squares. (Blast Furnace and Steel Plant, 1945, vol. 33, Mar., pp. 350-354). An illustrated description is given of two 24-in. roughing stands and four 18-in. finishing stands with auxiliary equipment which were recently shipped from the United States to Russia.

The Fundamentals of Wide Strip Rolling. W. Winkler. (Stahl und Eisen, 1943, vol. 63, Oct. 7, pp. 731-735). The theory and practice of the high-speed rolling of wide strip are discussed with special reference to the factors causing variations in thickness along and across the strip.

The Influence of Roll Diameter in the Cold-Rolling of Strip Steel. W. Lueg and A. Pomp. (Iron and Steel Institute, 1945, Translation Series, No. 247). An English translation is presented of a paper which appeared in *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1935, vol. 17, No. 5, pp. 63-76 (see *Journ. I. and S.I.*, 1935, No. II., p. 407).

The Influence of the Material of the Rolls, the Speed of Rolling, the Strip Width and Previous Cold Deformation on the Cold-Rolling of Strip Steel. W. Lueg and A. Pomp. (Iron and Steel Institute, 1945, Translation Series, No. 248). An English translation is presented of a paper which appeared in *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1935, vol. 17, No. 20, pp. 219-230 (see *Journ. I. and S.I.*, 1936, No. I., p. 179 A).

Steel Discard.—Small-Scale Plant for Re-Working Scrap and Unfinished Material. A. G. Arend. (Iron and Steel, 1945, vol. 18, Sept., p. 415). A brief description is given of a small rolling-mill plant specially intended for rolling various forms of steel scrap into material suitable for forging spades, shovels, ploughshares, mattocks, &c., without having to remelt it.

Erecting and Putting in Commission a Plant to Produce Seamless Tubes. E. Wolff. (Stahl und Eisen, 1943, vol. 63, Aug. 19, pp. 589-593). A description, with numerous illustrations, is given of a tube mill designed by Schloemann A.-G. which was erected in Germany in 1938-39. The mill consists of reheating furnaces, piercers, two reducing trains comprising a light train for tubes from 17 to 168 mm. outside dia. and a heavy train for tubes from 127 to 343 mm. outside dia., and cooling beds. Machinery of very modern design was incorporated, especially in the heavy mill.

Possibilities of Increasing the Quality of Rolling-Mill Products. G. Juretzek. (Stahl und Eisen, 1943, vol. 63, Sept. 23, pp. 689-695). The steps taken in American rolling-mills, producing spring steel for automobiles, to improve the quality of the product, are described. These include promoting the co-operation of labour by various incentives and technical improvements to guides and guards and the use of high-pressure water (at 70-90 atm.) for descaling.

PYROMETRY

(Continued from p. 111 A)

Temperature Control of Heat-Treatment Furnaces. E. E. Cook. (Institute of Fuel War Time Bulletin, 1945, Aug., pp. 237-244). A brief survey of the types of temperature-controlling instruments available for heat-treatment furnaces, with notes on the limitations of each type, is presented and some indication of the correct form of control to use for various duties is given.

Temperature of Molten Steel Measured with Immersion Thermocouple. (Iron Age, 1945, vol. 155, Feb. 22, p. 65). A description is given of a modification of the Schofield-Grace quick-immersion thermocouple developed by the Rustless Iron and Steel Corporation. The temperature of the steel is indicated and recorded by an electronic device.

Temperature of Steel Bath Measured in Five Seconds. (Blast Furnace and Steel Plant, 1945, vol. 33, June, pp. 712-713). A brief description is given of the Collins-Oseland pyrometer for determining the temperature of liquid steel. This is an optical form of pyrometer in which the radiation from the steel is measured by a photo-electric cell connected to amplifying and recording instruments. The cell is mounted at the back of a 6-ft. length of steel tube the front end of which is thrust below the slag layer in the furnace. The tube is kept clear by a current of compressed air.

Temperature-Indicating Paints. L. C. Tyte. (Proceedings of the Institution of Mechanical Engineers, 1945, vol. 152, No. 2, pp. 226-231). The requirements to be satisfied by temperature-indicating pigments are stated and the development of pigments to meet this specification is described. Factors influencing the temperature-colour relationships, the application of the paints and the recording of results are discussed. Paints have been developed which enable temperature determinations to be made with an error not exceeding $\pm 5^{\circ}\text{C}$.

HEAT-TREATMENT

(Continued from pp. 138 A-140A)

Continuous Heat-Treatment of Bars by High-Frequency Induction. (Machinery, 1945, vol. 67, Sept. 13, pp. 281-284). Machines for the continuous heat-treatment of bars by induction heating are described and illustrated. For hardening at, say, $830-870^{\circ}\text{C}$., bars may be fed through the machine at speeds of from 20 to 60 in./min. The speed is adjusted so that for any particular size of bar the required temperature is reached as it leaves the inductor and enters the quench.

Effect of Various Surface and Structural Conditions on Nitriding. F. F. Dodson. (Metallurgia, 1945, vol. 32, Aug., pp. 149-151). See abstract of paper entitled "Some Experiments in Nitriding," p. 139 A.

The Annealing of Steels after Hardening from the Heat of Rolling. R. Walzel, R. Werner and A. Schneider. (Stahl und Eisen, 1943, vol. 63, July 15, pp. 489-494). The effects of three different treatments on the hardness, microstructure and machinability of ten copper-bearing steels with carbon contents over the 0.37-1.08% range, some alloyed with chromium and nickel, were investigated. The treatments consisted of: (a) Annealing after cooling on the cooling bed in the ordinary way; (b) annealing after hardening from the heat of rolling; and (c) annealing after hardening by specially heating and quenching. In general, treatment (b) produced a greater Brinell hardness in the low-carbon steels and a lower

hardness in the high-carbon tool steels than either treatment (a) or (c). The structure after treatment (b) was the most uniform and consisted of fine spheroidal cementite. The machinability of steels of equal hardness was best after treatment (b).

Atmospheres for Annealing Metals. C. E. Peck. (Metals and Alloys, 1945, vol. 22, July, pp. 85-91). The following types of heat-treatment furnace atmospheres are discussed with details of the equipment used to produce them, their applications and the costs of production: (1) Completely burned fuel gas; (1a) completely burned fuel gas with CO_2 and H_2O removed; (2) partially burned fuel gas; (2a) partially burned fuel gas with the CO_2 and H_2O removed; (3) dissociated ammonia; (4) partially burned dissociated ammonia; (4a) completely burned dissociated ammonia.

Alloy Steel Bars.—Electric Furnaces for Hardening and Tempering. (Iron and Steel, 1945, vol. 18, Sept., pp. 439-440). A new all-electric hardening and tempering plant for alloy steel bars, consisting of two furnaces, two quenching tanks and a special high-speed electric charging machine, is described.

WELDING AND CUTTING

(Continued from pp. 140 A-142 A)

A Large Forged Spot-Welding Machine. (Engineer, 1945, vol. 180, Oct. 5, pp. 270-271). An illustrated description is given of a spot-welding machine for joining fairly heavy mild-steel plates and sections. With it, plates are first fused locally between electrodes, as in the normal spot-welding process, and then, while the metal is still red hot, the plates are moved along to bring the weld point between two pressure pads capable of applying a load of up to 80 tons.

Flash Welding Alloy-Steel Rings. P. B. Scharf. (Iron Age, 1945, vol. 156, Aug. 16, pp. 50-53). A description is given of the flash butt-welding of steel rings of large diameter but small section of very hard steel containing 1% of carbon and 1.5% of chromium.

Brazing of Heat-Treated Parts. (Iron Age, 1945, vol. 156, Aug. 16, pp. 54-55). A method of silver-soldering tubular steel parts in a furnace is described. These parts, used in aeroplane construction, were of heat-treated 1%-chromium steel. The silver-soldering was carried out at 1200° F., and the joint had very high tensile and shear strengths after the operation.

Metal Joining Processes: Their Choice and Control. J. L. Miller. (Engineering Inspection, 1945, vol. 10, Summer Issue, pp. 26-31). Riveting, soldering, brazing and welding processes, their selection and methods of control are briefly described.

The Weldability of Steel Sheets and Its Determination. F. Eisenkolb. (Stahl und Eisen, 1943, vol. 63, Aug. 5, pp. 553-557). A method of testing the weldability of steel sheets is described and the results obtained with it on sheets from 1 to 2 mm. thick are presented and discussed. The test is made by remelting the steel along the centre line of a 90-mm.-wide strip using an oxy-acetylene welding torch with a neutral flame; no filler metal is applied. After the specimen has cooled, a series of deep-drawing cup tests are made alternately on each side of the remelted zone, and the weldability is judged by the values obtained. Poor weldability was found for steels high in carbon and sulphur, whilst silicon-killed steel gave good results.

Effect of Heat upon Residual Stresses. La Motte Grover. (Iron Age, 1945, vol. 156, Aug. 16, pp. 62-69). Methods of calculating residual

stresses in bars and plates set up by expansion and contraction during welding and after subsequent heat-treatment are discussed with examples.

Proposed Engineering Bulletin and Shop Procedure for Repairing Malleable Iron Castings. (American Foundryman, 1945, vol. 8, Aug., pp. 72-76). Specifications for methods of repairing castings are being drawn up by the Society for Automotive Engineers in conjunction with other interested authorities. The present article consists of the code, prepared in the form of an Engineering Bulletin, for shop procedures for repairing malleable iron castings.

Welding Methods for Gray Iron Castings. L. F. Granger. (American Foundryman, 1945, vol. 8, Aug., pp. 60-64). Methods of repairing iron castings by welding with cast-iron filler metal and with bronze are described with examples.

Binding Agents for Flux Coatings. W. Andrews. (Welding, 1945, vol. 13, July, pp. 263-268; Aug., pp. 307-312). The author discusses recent developments in the application of alternative inorganic binding agents for the flux coatings of metallic arc electrodes and welding rods.

Trepanning Welded Joints for Defects. J. B. Arthur and M. H. MacKusick. (Iron Age, 1945, vol. 156, Sept. 6, pp. 80-82). An account is given of the system adopted at a Californian shipyard for trepanning plugs of metal from welded joints as a means of inspecting and controlling the welding procedure.

CLEANING AND PICKLING OF METALS

(Continued from pp. 115 A-116 A)

Trichlorethylene Economy in Degreasing Metal Parts. A. A. Angus. (Mechanical World, 1945, vol. 118, Aug. 24, pp. 221-222). A degreasing plant operating on the Fraser-Heller system is described. This plant incorporates an activated carbon unit for recovering the trichlorethylene. As the system is completely enclosed no harmful vapours escape into the shop, and about 90% of the trichlorethylene is recovered.

Inhibitors for the Protection of Iron when Pickling. B. Israelson. (Teknisk Tidskrift, 1945, vol. 75, Sept. 8, pp. 983-989). (In Swedish). The theories of various investigators of the effects of inhibitors are discussed and methods of measuring corrosion-inhibiting capacity are described. An extensive bibliography and a list of patents covering the period 1937-1944 are appended.

COATING OF METALS

(Continued from pp. 116 A-119 A)

Improved Techniques Produce Superior Stainless Clad Steel. L. W. Townsend. (Steel, 1945, vol. 117, Aug. 20, pp. 145-150). Methods of cladding plates of carbon steel and low-alloy steel with sheets of stainless steel are briefly described.

The Chemical Control of the Hot-Dip Galvanizing Process. F. F. Pollak and E. F. Pellowe. (Sheet Metal Industries, 1945, vol. 22, Aug., pp. 1349-1355). The chemical methods of control employed at a large hot-dip galvanizing plant are described in detail. Particulars are given of the pickling, fluxing, drying and galvanizing practice and of the procedures for the chemical analysis of pickling and flux solutions, etching solution and spelter.

The Technique of Sheet Galvanizing by the Hot Dip Process. H. Edwards. (Sheet Metal Industries, 1945, vol. 22, Sept., pp. 1546-1552).

An account is given of the pickling and galvanizing plant and practice at the works of John Summers and Sons, Ltd. The description includes details of the mechanical equipment used.

Tests on Iridite Finish for Cadmium and Zinc Plated Steel. K. E. Dorcas and N. H. Simpson. (*Iron Age*, 1945, vol. 156, July 26, pp. 61, 143). Salt-spray tests are described which proved that the corrosion resistance of zinc-plated and cadmium-plated steel was considerably improved by treating the specimens in iridite solution.

Metallizing—A Production Process. L. E. Kunkler. (*Metals and Alloys*, 1945, vol. 21, June, pp. 1649–1651). The metallizing or metal-spraying process is described with several examples of its application to parts made of metal, wood and plastics.

A Simple Magnetic Tester for Determining the Thickness of Coatings on a Steel Base. E. S. Spencer-Timms. (*Journal of the Electrodepositors' Technical Society*, 1945, vol. 20, pp. 139–146). A simple magnetic testing device is described with which the thickness of non-magnetic coatings on iron and steel can be measured. This instrument uses the "steel-yard" balance principle to measure the force required to detach one pole of a small permanent magnet from the coated steel. The thickness of the coating is then derived from calibration curves prepared with the aid of standard specimens.

Boron-Free Ground-Coat Enamel Using Slag from the Soda-Desulphurization Process. M. Paschke and H. Kohl. (*Stahl und Eisen*, 1943, vol. 63, June 30, pp. 476–478). The possibilities of making use of the slags arising from the soda-desulphurization process are briefly reviewed, and experiments are described which indicate that this slag can be used in enamel frits for ground coats because it lowers the surface tension of the molten frit and gives it good wetting properties without any boron compounds being required.

How to Get the Most from Infra-Red Heating, Drying, Baking. G. W. Birdsall. (*Steel*, 1945, vol. 117, Aug. 6, pp. 116–119, 148–156). The principles of infra-red-ray heating are explained and its application for drying painted and enamelled articles is described with notes on factors which increase the efficiency of the process; such factors include enclosing the lamps and work in a chamber to prevent heat being lost by convection currents and having a holding zone with a much smaller number of lamps than in the heating zone. Conveyor systems for carrying the work between banks of lamps are also described.

PROPERTIES AND TESTS

(Continued from pp. 142 A–147 A)

What Are the Essential Fundamental Properties which Define a Material's Strength Properties? C. Benedicks. (*Jernkontorets Annaler*, 1945, vol. 129, No. 9, pp. 557–570). (In Swedish). The properties of steel as defined by the International Congress on the Testing of Materials (Zürich, 1931) and in the Swedish Standards for Steel (SMS 2002, 1937) are discussed and the author endeavours to answer the questions: (1) What are the fundamental properties necessary and sufficient to characterize the hardness and strength of a material? (2) What are the relationships between these fundamental properties and the other static strength properties? He presents a simplified stress-strain diagram for a homogeneous material and defines four essential properties as follows: (1) The elastic hardness is the greatest stress a material can withstand without permanent deformation; (2) the plastic hardness is the stress a material can withstand after

a given permanent deformation; (3) the elasticity of a material is the greatest tensile stress it can withstand without permanent deformation; and (4) the tenacity of a material is the greatest tensile stress it can withstand without breaking.

Fridman's Theory of Strength of Materials. G. S. Smith. (*Metallurgia*, 1945, vol. 32, Aug., pp. 163-171). The Russian author Ya. B. Fridman in a recent book "A United Theory of the Strength of Materials" claims to unite the various theories for the strength of materials by resolving their apparent contradictions as well as to provide the possibility of indicating on a single diagram all the possible stress states of a material. Many aspects of the unified theory are acknowledged by the author as requiring further proof by specially designed experiments. An attempt is made in the present paper to give an account of Fridman's theory and diagrams.

Tessellated Stresses.—Part IV. F. László. (Iron and Steel Institute, 1946, this Journal, Section I). The criterion of making units of structural tessellation self-compensated is found to be the equality of the shear moduli of elasticity of the components. Tessellated yield is analysed for lamellar and spherical structures, and iron and steel are discussed in this regard. The possible influence of tessellated stresses and yield on the reshaping of structural components by annealing is investigated. An argument based on the consideration of inter-atomic tessellated stresses is offered in support of the explanation of precipitation-hardening by the "blocking of potential slip planes." Some problems connected with magnetization are discussed, and the question of internal friction is touched upon with reference to tessellated stresses.

Structural Premises of Strain Hardening and Recrystallization. C. H. Mathewson. (Campbell Memorial Lecture: Transactions of the American Society for Metals, 1944, vol. 32, pp. 38-87). An account is given of the early history of investigations which sought to clarify the macroscopic aspects of plastic deformation, but failed to reveal in the slip mechanisms postulated a generally accepted cause of strain-hardening. It is suggested that the slipping process is far more complicated than hitherto assumed, and that an observed slip direction is merely the resultant of movements in which the atoms find paths of lower potential than the direct route over barriers set by their own volume requirements. This point of view is supported by an X-ray study of the lattice rotations of crystallites in a single crystal of aluminium strained by axial loading wholly within the range of operation of a single slip system, and by the types of rotation necessary to adjust recrystallized grains of aluminium or brass to the orientation of the original single crystal from which they were derived by annealing after a small plastic extension.

The Comparison between the Tendencies towards Austenitic Grain Growth in Unwrought and Forged Steel. P. Bastien. (*Revue de Métallurgie, Mémoires*, 1941, vol. 38, Feb., pp. 44-49). The author endeavours to answer the question as to whether a coincidence exists between the initial austenitic grain size in steel as-cast and that of the same steel after forging. The propensity towards grain growth in these two states was also investigated. Small ingots (8 kg.) of basic open-hearth carbon steel (carbon 0.36%) derived from two casts with additions of 0.04% and 0.125% of aluminium, respectively, were used for the experiments. The conclusions reached were: (1) The coarse grains appear at a considerably higher temperature in the unwrought than in the forged steel; (2) small differences in the size of fine grains can exist without being systematic; (3) the size of coarse grains is practically the same for both states, but the unwrought steel shows a greater heterogeneity; and (4) the McQuaid-Ehn test on samples of unwrought steel is a good method of determining its capacity for regeneration by thermal refinement.

The Influence of Radial Pressure between Members of a Press Fit in Initiating Fatigue Failures. G. W. C. Hirst. (Journal of the Institution of Engineers, Australia, 1945, vol. 17, June 30, pp. 101-105). Theories for the causes of failure of axles within the hubs of press-fitted wheels are discussed and the following conclusions are arrived at: (1) The radial pressure from the hub causes a tensile stress in the surface of the axle outside the effective bearing area of the hub near to its edge; (2) fatigue cracks are caused by alternating stresses developed in the surface of the axle; (3) the presence of the stresses referred to in (1) and (2) does not, in general, appear to be sufficient to initiate fatigue fractures; (4) fatigue fractures appear only in the abraded part of the wheel seat, the abrasion or fretting being caused by the very small movement between the surfaces of the wheel seats and hubs and this apparently lowers the endurance limit of the metal; and (5) fatigue cracks in the wheel seats of steel axles are believed to occur only with axles fitted with steel wheel centres, not when the wheel centres are of cast iron.

The Effect of the Velocity in the Cold-Deformation of Steels on the Basis of Investigations with the Rolling Hardness Tester. H. Hauttmann. (Stahl und Eisen, 1943, vol. 63, Sept. 2, pp. 641-647). A detailed description is given of a rolling-ball hardness testing machine in which a ball 2.5 mm. in dia. is moved over the specimen under a constant load of 80 kg. The machine is designed so that the speed of the ball can be controlled within the range of 0.2-1000 mm./sec., and track lengths up to 100 mm. can be made on the specimen. The width or depth of the track is measured, and this is converted to Brinell hardness units by a calibration curve. The effect of the deformation velocity on thirty-four steels was studied and the following conclusions were reached: (1) In the velocity range investigated, the deformation resistance and the hardness increased linearly with the logarithm of the deformation velocity; (2) the effect of the deformation velocity was independent of the alloying elements and heat-treatment, but dependent on the tensile strength; (3) at the higher rates of deformation the logarithm of the percentage increase in the deformation resistance and of the hardness increased linearly with the logarithm of the tensile strength; and (4) an increase in the elongation and reduction of area slightly decreased the velocity effect.

Relationship between the Brinell (and Vickers) Hardness and the Tensile Strength of Steels. H. Staudinger. (Stahl und Eisen, 1943, vol. 63, July 29, pp. 537-539). Hardness and tensile tests were made on steels with 0.17-0.60% of carbon and on some low-alloy steels to study the relationship between the two properties. It was found that for steels with tensile strength in the 80-150 kg./sq. mm. range a fairly accurate determination of the tensile strength was obtained by dividing the hardness value by 3.

A Relationship between Hardenability and Tensile Strength of Normalized Steels. L. A. Carapella. (Transactions of the American Society for Metals, 1945, vol. 35, pp. 435-445). Three equations are derived relating to the hardenability of normalized steels. They express: (1) The hardenability as the ratio of the hardness after quenching in water to the hardness resulting from a particular rate of cooling; (2) the hardness after quenching in water in terms of the carbon content; and (3) the hardness as a function of the tensile strength.

Non-Destructive Methods of Inspection. H. Jolivet. (Revue de Métallurgie, Mémoires, 1941, vol. 38, June, pp. 153-163). The author describes the magnetic-powder method of detecting defects in steel. The indications produced by the magnetic powder are not all due to defects. In some cases it is not possible to find an explanation for the accumulation of the magnetic powder. The author, therefore, stresses the necessity of a correct interpretation of the results obtained by this method. He

illustrates several examples of detectable defects, and classifies them as follows: Very fine cracks, cavities of noticeable width, segregation, heterogeneity of composition, and heterogeneity caused by the existence of regions of different permeability.

Crack Detection by Fluorescence. (British Engineering Export Journal, 1945, vol. 28, July-Aug., p. 72). A description is given of the Metrolux crack-detecting apparatus. It consists of an inspection cabinet in which the parts, previously dipped in a solution of fluorescent material, are bathed in ultra-violet light. A tank, divided into three compartments for impregnating, cleaning and drying, is also supplied.

Increased Use of Gray Cast Iron in High Temperature Operations. C. O. Burgess and T. E. Barlow. (American Foundryman, 1945, vol. 7, May, pp. 57-65). There are certain Codes in force in the United States which specify that cast iron shall not be used at temperatures above 450° F. The War Metallurgy Committee of the War Production Board reports on the results of a survey which was made by sending a questionnaire to many users of cast iron at high temperatures. The almost unanimous desire was expressed that the 450° F. limit should be raised to the 600-750° F. range. The data obtained on the properties of cast iron at high temperatures are presented and discussed.

The Effect of the Microstructure as Affected by the Heat-Treatment and Alloying Elements on the Creep Strength of Steel. H. Bennek and G. Bandel. (Stahl und Eisen, 1943, vol. 63, Sept. 9, pp. 653-659; Sept. 16, pp. 673-684; Sept. 23, pp. 695-700). Short-time and long-time tests were made on a large number of carbon and low-alloy steels to study the effect of the ferrite and A.S.T.M. grain sizes resulting from different methods of production and heat-treatment on the creep strength. An increase in grain size is not the sole direct cause of improvement in creep strength. In plain carbon steels the effect on the creep strength is due to a precipitation phenomenon the exact mechanism of which has not yet been explained. Tests with heat-treated low-alloy steels showed, contrary to expectation, that those with intermediate structures, even after tempering at far above the creep-test temperature, always had a higher creep strength at 500° C. than those with a tempered martensitic structure. The steels with the softer ferrite-pearlite structure were, generally speaking, considerably lower in creep strength. In order to obtain the optimum structure by transformation in the intermediate stage it is necessary to determine and apply the correct cooling velocity for the section and grain size of the particular steel. A bibliography of 88 references is presented.

New Heat-Resisting Iron. (Iron Age, 1945, vol. 156, Aug. 16, p. 75). Curves show the changes in tensile strength and elongation with temperature in the 100-1700° F. range of three new heat-resisting cast irons known as Alten's Alloys. Nos. 11, 15 and 18 are presented. These are high-silicon irons, No. 18 containing 1% of chromium and No. 15 with 1.5% of chromium and 0.58% of molybdenum.

Sealing Resistance of Hard-Facing Alloys Having Various Cobalt Contents. H. Cornelius. (Iron and Steel Institute, 1945, Translation Series, No. 250). An English translation is presented of a paper which appeared in Stahl und Eisen, 1944, vol. 64, Aug. 17, pp. 529-532 (see Journ. I. and S.I., 1945, No. I., p. 60 A).

Research on the Mechanism of Hydrogen Embrittlement of Steel.—I. The Mechanism of the Phenomenon in Very Soft Annealed Steel. P. Bastien. (Revue de Métallurgie, Mémoires, 1941, vol. 38, Sept., pp. 225-238; Oct., pp. 272-284). The author reviews some recent research work on the embrittlement of steel by hydrogen, and presents the results of his own investigations. Tests were made with 2-mm.-dia. wire of soft steel

(carbon 0.065%) by registering the number of bends in an Amsler machine after pickling under various conditions which might occur in practice. The author draws the following conclusions, which are valid for soft steel in an annealed state: (1) The hydrogen embrittlement diminishes progressively with time, and the speed of this process depends on the nature and temperature of the medium in which the recovery takes place; (2) in general, rapid and complete disappearance of embrittlement is effected by immersing the pickled material in cold water, or by exposing it to air at 100–300° C.; (3) complete recovery does not take place if the amount of hydrogen diffused into the material exceeds a certain critical value; (4) under normal conditions, when the pickling period does not exceed 48 hr., the diffused hydrogen is concentrated in the peripheral zone without reaching the core; and (5) the best embrittlement test is the determination of the number of bends before fracture.

Tungsten in Cast Iron. S. W. Palmer. (Bulletin of the British Cast Iron Research Association, 1945, vol. 28, July–Aug., pp. 55–58). The literature on the effect of tungsten in cast iron is reviewed. Tungsten is essentially a carbide stabilizer, although it is not so effective as chromium. It has a marked stabilizing effect on combined carbon during the heat-treatment of cast iron. Tungsten increases the transverse and tensile strengths of cast iron, but the increase is greater for 1–2% of tungsten than for additions of up to 1%. Tungsten moves the iron-carbon eutectoid point to the left, not so far as chromium and manganese, but further than nickel.

Vanadium in Cast Iron. J. W. Grant. (Bulletin of the British Cast Iron Research Association, 1945, vol. 8, Sept., pp. 50–54). A review of the literature on the effects of vanadium on the properties of cast iron is presented. The following conclusions are drawn: (1) Vanadium additions improve the mechanical properties of cast iron to a degree not exceeding 25%; (2) vanadium behaves as a carbide stabilizer and is considered to be more potent than chromium in this respect; (3) the hardness is increased by about 15–20 Brinell points for each 0.1% of vanadium; (4) small additions of vanadium increase the depth and hardness of the chill; (5) the claim that vanadium improves the wear-resisting properties is not substantiated; (6) additions of up to about 0.3% are generally sufficient; (7) the additions may be made as finely powdered ferro-vanadium at the cupola spout, in which case the vanadium losses are about 20–25%; and (8) the shrinkage and contraction are only slightly affected by the additions.

High Strength Steels for Light-Weight Structures. F. D. Foote. (Metals and Alloys, 1945, vol. 22, July, pp. 92–99). The properties of copper-bearing steels and low-alloy, high-tensile steels are considered with special reference to their suitability for constructing railway trucks for coal and to the saving in dead weight which can be achieved by their use in transport equipment.

Ball and Roller Bearing Steels. H. T. Morton and E. E. Wagner. (Steel, 1945, vol. 117, Aug. 27, pp. 100–102, 144–146). In order to simplify the many American specifications for ball- and roller-bearing steels, the Technical Advisory Committee on Carbon and Alloy Steel Bars appointed by the War Production Board approved of three analyses of steel N.E. 52100 which were to replace the twenty-seven formerly used. Details of these analyses and the appropriate heat-treatments are discussed.

NE Steels for Steering Nuckles and Axle Drive Shafts. J. H. Clark, J. D. Walker and A. S. Jameson. (Metal Progress, 1945, vol. 48, Aug., pp. 280–287). Particulars are given of the methods devised for testing tractor steering knuckles and driving shafts made of high-manganese low-chromium steels such as S.A.E. 4145, N.E. 9450 and N.E. 8650H.

Steels for Castings. L. Sanderson. (Engineering and Boiler House Review, 1945, vol. 59, July, pp. 173-175; Aug., pp. 216-218). The properties of heat and corrosion-resisting cast steels used in boiler plant and electric power stations are reviewed.

German Tool and Special Steels. J. P. Gill. (Iron Age, 1945, vol. 156, Sept. 13, pp. 54-A-54-N; Steel, 1945, vol. 117, Sept. 24, pp. 120-132). Particulars are given of the brands and analyses of a large number of German tool and special steels made by the five principal German steel producers.

Talks About Steelmaking—Shaping Specifications. H. Brearley. (British Steelmaker, 1945, vol. 11, Sept., pp. 400-408). The drawing-up of steel specifications is discussed and some existing specifications are criticised.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 148 A-149 A)

The Resolving Power of the Magnetic Electron Microscope. V. E. Cosslett. (Journal of Scientific Instruments, 1945, vol. 22, Sept., pp. 170-174). The chief factors limiting the performance of electron microscopes are discussed. These are: Spherical and chromatic aberration, diffraction, and imperfections in lens construction. Methods of approach to the correction of aberrations are reviewed. It appears preferable to proceed from the fundamental equations of electron motion, with the use of relaxation methods. Even if the mechanical difficulties in lens construction are overcome, a very great reduction in spherical aberration is required to improve the resolution to below 10 Å. Further reduction in chromatic aberration is unnecessary at present.

Electrolytic Polishing of Metals. Its Present State of Development and Application. P. A. Jacquet. (Revue de Métallurgie, Mémoires, 1940, vol. 37, Sept.-Oct., pp. 210-224; Nov.-Dec., pp. 244-262). The methods of electrolytic polishing and results obtained, as described in various periodicals, are reviewed. After giving a historical outline of its development, the author describes the practical conditions for electrolytic polishing. The apparatus, the physical factors in electrolysis, the preparation of surfaces and their treatment after polishing, and the manipulation of solutions are described. He then deals with methods of electrolytic polishing applied to various metals, such as copper and aluminium and their alloys, lead, cobalt, nickel, zinc, tungsten and finally iron and steel. As regards the latter, two methods are specified: E. W. Elmore's, using phosphoric acid, and his own, applying perchloric-acetic acid solution. The industrial polishing of stainless steels, nickel and aluminium is also described. Various applications of electrolytic polishing are given, of which the widest is the preparation of samples for microscopic examination. A table gives the composition of the electrolytes, the conditions of electrolysis and the results obtained after the polishing of Armeo iron and different kinds of steel.

Electrolytic Polishing and the Attack in Ten Seconds. A. De Sy and H. Haemers. (Revue de Métallurgie, Mémoires, 1941, vol. 38, May, pp. 122-128). The authors described a rapid method of electrolytic polishing, evolved by them and based on the method of P. A. Jacquet. They use as electrolyte a solution of perchloric acid and methyl alcohol. The original surface condition, the voltage and the current density are given in detail, as well as results, illustrated by micrographs, which the authors obtained on samples of aluminium and its alloys, and of carbon and special steels.

Electrolytic Polishing. (Steel, 1945, vol. 117, Sept. 10, pp. 104-106). The present stage in the development of methods of electrolytic polishing is reviewed.

Steel Castings Radiography. E. L. LaGrelus and C. W. Stephens. (American Foundryman, 1945, vol. 7, May, pp. 49-56). The principles of the X-ray apparatus used for detecting faults in castings are simply explained. A number of defects are defined and seventeen radiographs showing defects are reproduced and discussed.

High-Speed X-Rays. C. M. Slack, C. T. Zavales and E. R. Thilo. (Steel, 1945, vol. 117, Sept. 3, pp. 114-117, 150-162; Sept. 10, pp. 120-122). The development of the Westinghouse cold cathode X-ray tube, the generator and circuits is described with details of its application for measuring impacts at high velocity with exposures down to 10^{-6} sec.

Sectional Radiography. R. Taylor. (Metals and Alloys, 1945, vol. 22, July, pp. 99-101). An X-ray technique for studying a layer of metal at a predetermined distance from the surface is described. The X-ray tube is moved during the exposure in a plane parallel to the layer to be studied and the strip of film behind the metal is held in a position such that the ratio of the distances from the tube and from the film to centre of the layer remains constant during the movement. Inclusions or other defects in the layer cast a sharply defined shadow across the film.

Micro-Examination of High-Silicon Irons. J. E. Hurst. (Iron Age, 1945, vol. 155, May 17, pp. 59-61, 153). After reference to the "barley shell" structure noted in high-silicon irons by M. G. Corson in 1941 the author describes his own experience with this structure when etching specimens of acid-resisting irons. The information given is the same as that in a recent paper by the author and R. V. Riley (*see* Journ. I. and S.I., 1945, No. I., p. 65 A).

Local Heating in Plain Carbon Steels. W. J. Wrazej. (Iron and Steel Institute, 1946, this Journal, Section I.). This paper describes the examination of certain samples of steel, parts of which had been subjected to various types of local heating, notably from the blast of hot gases and by friction. In each case a shallow martensitic layer was produced, and it is shown that the temperature reached the A_{c1} , but not the A_{c3} , point. The composition of eutectoid steel is considered and it is deduced that it contains 0.888% of carbon. The structure of martensite in eutectoid steel, its ease of production and possible reasons for its stability are also discussed.

BOOK NOTICE

(Continued from pp. 152 A-154 A)

HOARE, W. E., and E. S. HEDGES. "*Tinplate.*" La. 8vo, pp. viii + 292. Illustrated. London, 1945: Edward Arnold and Co. (Price 40s.)

The authors state in the preface that "considering the size of the industry it is somewhat surprising that hitherto there has been no book devoted entirely to the subject of tinplate." The present publication is a commendable effort to overcome this omission in technical literature. The preparation of the subject-matter by the authors coincided with the years during which the old method of production by hot-pack rolling was being seriously challenged by the new process of continuous rolling. Publication comes at a time when there is no doubt that the old methods will soon be only of historical interest. In view of this there may be some who feel that the space devoted to the hot-pack process is wasted effort; but, as the book is claimed to be the first extensive statement on tinplates, it would have been a definite omission if this aspect had been cut down too much.

There are twelve chapters and a statistical appendix covering 286 pages. The first chapter deals with the history of tinplate manufacture. Any reader who is not intimately associated with the manufacture of tinplates, may find the presentation of later chapters rather confusing. However, if a little time is occupied in mastering the descriptions of the hot-pack and the continuous cold-reduction processes on pp. 5 and 6, it will prove helpful. The second chapter, on

the steel base of tinplate, is short and gives some indication of the types and composition of steel generally used.

Chapter III. deals with hot-pack rolling and the next chapter with continuous cold-rolling. The continuous rolling methods are said to be a major development of recent years. "Major" seems a comparatively mild term for a process which is destined to supersede the old methods to their almost entire exclusion.

In chapter V., after some brief technical thoughts on rolling scales and theory of pickling, a description is given of the old plunger-type batch and modern continuous-type pickling machines. The following chapter on cold-rolling covers practice in the hot-pack process, with descriptions of cold reduction and temper rolling mills. Electrolytic degreasing is discussed in this chapter. Chapter VII. deals with annealing, where various types of furnace, mostly of recent design, are considered.

The description of the processes used in the manufacture of hot-dip tinplate are concluded in chapter VIII, which is on the tinning department. The authors are more at home here, and in the following three chapters on the structure of tincoatings, testing of tinplate, and corrosion of tinplate. The final chapter on electrotinplate serves as an introduction to this subject.

The book is noteworthy for the care taken by the authors in collecting their information and their acknowledgement of the various sources. The book can be recommended to all who are interested in tinplate, and more particularly to those who are concerned with its manufacture. The printing is clear and the subject-matter well illustrated by diagrams and photographs. There is an extensive bibliography at the end of each chapter, and an interesting statistical appendix.

P. M. MACNAIR.

ORES—MINING AND TREATMENT

(Continued from pp. 127 A–128 A)

New Metallurgical Experience with Sintering. B. Hessel. (Jernkontorets Annaler, 1945, vol. 129, No. 8, pp. 383–446). (In Swedish). The factors affecting the sintering of Swedish ores are considered and numerous tests carried out at a pan sintering plant which was put in commission at Hofors in 1940 are described, the test data being presented in tables and by graphs. To obtain a strong “black-burned” sinter of good reducibility it is necessary that a certain critical sintering temperature shall not be exceeded and that the charge is only held a short time at that temperature. To achieve this the charge must be loose and uniformly mixed, it must be simultaneously ignited over the whole surface, the fuel must be finely ground, and there must be a large throughput of air. The economies resulting from attention to these points at the Hofors plant are discussed.

Sinter Plants—Their Design and Operation. C. J. Duby. (Association of American Iron and Steel Engineers: Iron and Steel, 1945, vol. 18, Aug. pp. 379–382). See p. 77 A.

Sintering Equipment at Workington. (Iron and Coal Trades Review, 1945, vol. 151, Nov. 16, pp. 753–757). An illustrated description is given of the Greenawalt sintering plant at the Workington Iron and Steel Works which was primarily designed to sinter a mixture of 80% Sierra Leone concentrates and 20% pyrites residues, both of a very fine texture and difficult to sinter.

Agglomeration of Fine Taconite Concentrates. M. F. Morgan. (Steel, 1945, vol. 117, Oct. 1, pp. 132–138, 166–170). Reports on tests made with sintering and nodulizing plants with various kinds of ores are presented, with special reference to agglomerating finely ground low-grade ores of Minnesota in rotary kilns.

REFRACTORY MATERIALS

(Continued from pp. 128 A–129 A)

A New Method of Producing High Density Blast-Furnace Bottoms. F. M. Miller. (Blast Furnace and Steel Plant, 1945, vol. 33, Aug., pp. 984–985). The difficulties in the production of suitable blocks for use in blast-furnace bottoms are discussed. Owing to the high fire-shrinkage of suitable fireclays, the desirable characteristics, such as density, in the finished block have to be largely sacrificed to attain regularity of sizing. Objections to grinding are pointed out. It is claimed that, by use of the ramming technique described, high-density blocks can be used without cutting or sizing, and that the density of the blast-furnace bottom can be increased by 8–10%.

Failures of the Refractory Linings of Blast-Furnaces, and the Ramming of Carbon Aggregates. R. Klesper. (Iron and Steel Institute, 1945, Translation Series, No. 244). An English translation is presented of a paper which appeared in Stahl und Eisen, 1944, vol. 64, Dec. 7, pp. 774–781 (see Journ. I. and S.I., 1945, No. I., p. 118 A).

Furnace and Apparatus for Carrying Out Refractoriness-under-Load Tests on Firebricks. H. T. S. Swallow. (Transactions of the British Ceramic Society, 1945, vol. 44, July, pp. 93–100). A furnace and apparatus for carrying out refractoriness-under-load tests on firebricks is described. The main features are the use of pure alumina furnace parts and insulation throughout, and a resistance heater made of a platinum-rhodium alloy.

Steel Foundry Refractories. A. H. B. Cross. (Metal Treatment, 1945, vol. 12, Autumn Issue, pp. 183-192, 212). The application of refractory materials to steel production by the cupola/side-blown-converter process is discussed and some of the problems and technical achievements during the war are reviewed.

Further Experience for the Use of Permeable Refractories in Furnace Construction. R. H. Anderson, D. C. Gunn and A. L. Roberts. (Institute of Fuel War Time Bulletin, 1945, Oct., pp. 19-28). The theory of the use of permeable refractories in furnaces and a report on experience gained with such installations have already been published (*see* Journ. I. and S.I., 1945, No. I., p. 40 A, and this Journal, p. 50 A). This paper constitutes another report on experience gained in eight furnace installations working on this principle. The installations include small and large bogie-hearth furnaces and wire-patenting furnaces.

Refractories Performance Records. M. A. Fay. (Iron and Steel Engineer, 1945, vol. 22, Sept., pp. 101-105). The method employed by the Bethlehem Steel Company to record the performance of refractory bricks is described.

Developments in the Use of Lumnite Cement at Gary Works Coke Plant. J. E. Ludberg. (Blast Furnace and Coke Association of the Chicago District: Blast Furnace and Steel Plant, 1945, vol. 33, July, pp. 830-834). Experience in the applications of a refractory concrete called "Lumnite" at a coke-oven plant is discussed. A particularly useful application was for lining coke-oven doors, the design of which is described.

FUEL

(Continued from pp. 155 A-156 A)

Mechanical Maintenance in Steam-Electric Generating Stations. G. A. Porter. (Iron and Steel Engineer, 1945, vol. 22, Sept., pp. 80-82). The work involved in the maintenance of the machinery and fittings of a steam-turbine electric generating station is described.

Maintenance of Flow Meters. R. C. Ascher. (Iron and Steel Engineer, 1945, vol. 22, Sept., p. 87). Recommendations are made on the maintenance of flowmeters which operate by the measurement of the drop in pressure behind an orifice plate or other restrictive device built into the pipe line.

An Electrical Analogue of the Flow of Heat in a Regenerator System. K. Heindlhofer and B. M. Larsen. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1798: Metals Technology, 1945, vol. 12, Aug.). This paper describes a relatively simple apparatus which, through the close analogy between the flow of heat and of electricity, enables one to solve quickly and with satisfactory accuracy many complex problems of heat flow. An example of its application to regenerator calculations is given.

The Problem of Flame Radiation with Particular Reference to Melting Furnaces. T. F. Pearson. (Metal Treatment, 1945, vol. 12, Autumn Issue, pp. 139-145, 199). It is pointed out that stack losses and heat lost by radiation from the structure are not the only important factors in the problem of furnace efficiency. A third very important factor in melting furnaces is the heat transfer from the flame and walls to the stock. Means of increasing efficiency by modifying the flame are considered, and it is suggested that fuels could be classified on the basis of the weight ratio between the "luminosity carbon" (that obtainable chiefly from tar vapours and hydrocarbons) and hydrogen.

The Effect of Output on the Thermal Efficiency of Heating Appliances. M. W. Thring and J. W. Reber. (Journal of the Institute of Fuel, 1945, vol. 19, Oct., pp. 12-18). The performance curves of a fuel-fired heating system such as a boiler or metallurgical furnace are calculated by choosing the simplest assumptions which suffice to bring in all the main factors. Broadly, the assumptions are that the heat of combustion goes to the charge, to the walls of the combustion chamber, and to the flue. It is shown that if such a system is operated with gradually increasing heat input, the efficiency rises from zero at the point where the gases just leave the system at the working temperature, reaches a maximum as the relative effect of wall losses decreases, and subsequently falls off as the flue losses rise due to the limited heat-transfer coefficient between the gases and the charge. By a comparison with the empirical characteristic curves of boilers it is shown that these usually operate above the rating corresponding to the maximum obtainable efficiency, and from this the theory confirms the fact that their efficiency cannot be greatly affected by lowering the wall losses by better insulation.

Symposium on Measurement of Heat Absorption in Furnaces. (Industrial Heating, 1945, vol. 12, Mar., pp. 402-408; May, pp. 772-778, 806; June, pp. 946-952; July, pp. 1132-1138; Aug., pp. 1318-1320). A symposium was held recently by the American Society of Mechanical Engineers on "Methods of Measurement of Heat Absorption in Furnaces," at which the following papers were read:

Temperature Measurement of a Steel Slab under Normal Steel Plant Operation, by F. S. Bloom.

Measuring Heating Rates in the Charge in Furnaces, by V. Paschkis.

A New Method for Measurement of Fluid Flow Applicable to Studies of Convection Heat Transfer, by A. Kolin.

Thermal Conductivity of Laminated Metal, by J. L. Finck.

The Measurement of Heat Flow from Furnace Walls, by C. B. Bradley.

Iron Pyrites Recovery Plant at Horden Collieries. F. B. Champness. (G. E. C. Journal, 1945, vol. 13, Aug., pp. 178-184). An illustrated description is given of a plant at the Horden Colliery, Durham, for recovering iron pyrites from colliery refuse consisting of rejects from several wet and dry coal-cleaning plants. The plant separates the pyrites from the shale and coal and then separates the coal from the shale. Its capacity is about 30 tons/hr.

Cleaning Fine Coal. M. G. Driessen. (Institute of Fuel: Colliery Guardian, 1945, vol. 171, Oct. 19, pp. 471-475). The theory and practice of coal-cleaning with cyclone washers are discussed and tests with laboratory apparatus and a pilot plant at the Mining Research Department of the State Mines in Holland are described.

Welfare of the Coking Industry. J. T. Dunn. (Year-Book of the Coke Oven Managers' Association, 1945, pp. 146-160). The welfare requirements of a coke-oven plant are considered, and information is given on how to comply with the Factories Act, as well as on how to provide conditions which will attract youths into the coking industry.

Memorandum on Carbon Monoxide Poisoning. (Ministry of Labour and National Service, H.M. Stationery Office, May, 1945, Form 827). This Memorandum gives information on the hazards to which carbon monoxide gives rise and indicates suitable preventative measures the adoption of which would result in a reduction in the number of accidents caused by inhaling this gas.

Setting Up Stack Drafts on Combustion Cross-Regenerator Ovens. J. R. Purdy. (Blast Furnace and Coke Association of the Chicago District: 1945—ii

Blast Furnace and Steel Plant, 1945, vol. 33, Aug., pp. 973-975). A method of determining the settings of butterfly valves in the flues of coke-oven regenerators where two or three regenerators are interconnected is described.

Production of Ammonium Sulphate from Coke Oven Gas. F. Wethly. (Blast Furnace and Steel Plant, 1945, vol. 33, Aug., pp. 976-980). The production of ammonium sulphate of uniform crystal size from coke-oven gas, using saturators, is described and discussed.

Operational Experience with a Gas-Producer Plant with Subsequent Electric Gas Cleaning. E. Pechal. (Stahl und Eisen, 1943, vol. 63, Nov. 4, pp. 808-812). A description is given of a modern gas-producing plant comprising five rotary-grate producers 2.6 m. in dia. with separate electrostatic cleaners for tar and oil. The plant has a productive capacity of 15,000 cu. m./hr., and 1000 kg. of coal produces 1.9-2.2 cu. m. of gas at N.T.P. Operating data are presented and discussed.

Cleaning Blast-Furnace Gas. (Coke and Smokeless-Fuel Age, 1945, vol. 7, Sept., pp. 169-182). Recent American experience in the cleaning of blast-furnace gas by wet and dry methods is discussed.

The Removal of Hydrogen Sulphide from Fuel Gases. G. U. Hopton and R. H. Griffith. (Institution of Gas Engineers, 1945, Communication No. 288). An account is given of an investigation of the behaviour of the seven molecular forms of ferric oxide, when used to remove hydrogen sulphide from coal gas.

Disposition of Coke-Oven Gas and Blast-Furnace Gas at Warren Plant, Republic Steel Corporation. P. E. Leiss. (Iron and Steel Engineer, 1945, vol. 22, Aug., pp. 71-73). A description is given of the manner in which the coke-oven gas is distributed at the Warren Plant of the Republic Steel Corporation. The arrangement of the mixing station for natural gas and air is also shown.

Disposition of Coke-Oven Gas and Blast-Furnace Gas at Johnstown Plant, Bethlehem Steel Company. H. C. Cox. (Iron and Steel Engineer, 1945, vol. 22, Aug., pp. 73-75). As there is no coke-oven gas-holder at the Johnstown Plant of the Bethlehem Steel Co., the consumption is regulated to suit the production. Extensive use of signalling systems is made, and the organisation is briefly described.

Disposition of Coke-Oven Gas and Blast-Furnace Gas at Clairton Works, Carnegie-Illinois Steel Corporation. R. A. Lytle. (Iron and Steel Engineer, 1945, vol. 22, Aug., pp. 75-77). The flow of coke-oven gas through various parts of the by-product plant and its distribution to the coke-ovens, open-hearth furnaces, soaking pits and reheating furnaces at the works of the Carnegie-Illinois Steel Corporation are described.

Disposition of Coke-Oven Gas and Blast-Furnace Gas at Campbell Works, Youngstown Sheet and Tube Co. H. B. Helm. (Iron and Steel Engineer, 1945, vol. 22, Aug., pp. 77-78). The distribution of fuel gases at the works of the Youngstown Sheet and Tube Co. is described. Surplus coke-oven gas is delivered to a 360,000 cu. ft. gas-holder at the rate of 1,400,000 cu. ft./hr. From here it passes through the mixing-station, and is delivered to the system at $4\frac{1}{4}$ lb./sq. in. The functions of the "gas dispatcher" are considered in detail.

Disposition of Coke-Oven Gas and Blast-Furnace Gas at Pittsburgh Works, Jones and Laughlin Steel Corp. L. F. Kopsa. (Iron and Steel Engineer, 1945, vol. 22, Aug., pp. 78-79). The method of balancing the supply and demand for coke-oven and blast-furnace gas at the steelworks of the Jones and Laughlin Steel Corporation is described. There is no gas-holder at these works, and tar is used as an auxiliary fuel when the demand exceeds the supply.

Safety Procedure in Cleaning and Repairing Tanks, Gas Holders, Vessels and Lines. (Iron and Steel Engineer, 1945, vol. 22, Aug., pp. 81-88).

This paper was prepared by a committee of plant officials of the Bethlehem Steel Company. The fundamental safety precautions to be observed in the cleaning of tanks, gas-holders, etc. are dealt with first. Procedures are then outlined for a number of cases, such as units containing (a) light oil, benzol or petrol; (b) tar, or heavy fuel oil; (c) combustible gases; (d) sulphuric acid; and (e) ammonia. Finally, first-aid treatments are described.

PRODUCTION OF IRON

(Continued from pp. 157 A-158 A)

Effect of Moisture Additions to the Air Delivered to Blast Furnaces. L. E. Riddle. (Eastern States Blast Furnace and Coke Oven Association: Blast-Furnace and Steel Plant, 1945, vol. 33, Aug., pp. 965-970). Experience gained in making controlled additions of steam to blast-furnace blast at the works of the Carnegie-Illinois Steel Corporation is discussed and compared with that of other works. The author has found that: (1) The production of iron decreases by 0.5% and the coke consumption increases by 1.2% for each grain of moisture added; (2) there is no significant difference in the smoothness of working, the production of flue dust, or the analysis of the iron produced; and (3) making controlled moisture additions to the blast cannot be justified from an economic standpoint.

Tests with Oxygen-Enriched Blast on Rich and Lean Burdens. W. Lennings. (Stahl und Eisen, 1943, vol. 63, Oct. 21, pp. 757-767). Blast-furnace tests are described the object of which was to determine the optimum conditions for smelting lean German ores with oxygen-enriched blast. The furnace used was 46 ft. high, with a hearth 7 ft. 9 in. in dia. In the two cases (a) with a burden of 100% lean German ores, and (b) with a mixture of rich and lean ores such that each supplied 50% of the iron content, the use of oxygen-enriched blast greatly increased the production, and, provided certain conditions were adhered to, there was a marked decrease in the coke consumption. To obtain the greatest efficiency when using oxygen it is necessary to prepare the ore by roasting or sintering, and to use burnt lime instead of limestone. With a dense burden of low permeability the reduced total quantity of gas resulting from the use of oxygen permits the stock to descend easily, and leads to uniform furnace operation. With only a small decrease in the coke consumption the use of oxygen was considered to be a paying proposition because of the increase in the productive capacity of the furnace.

Maximum Economical Blowing Rates. R. S. Wilcox. (Blast Furnace and Coke Association of the Chicago District: Blast Furnace and Steel Plant, 1945, vol. 33, Aug., pp. 986-990). The general economics of blast-furnace operation and, in particular, the effect of flue-dust production on these economics are described. By consideration of data from a normal two-year period and the construction of graphs, an optimum blowing rate for economical blast-furnace operation is calculated. It is concluded that the most economical blowing rate is that slightly above the point where the flue-dust production rate begins to increase rapidly. This blowing rate is influenced by the grade of iron and the furnace size.

Immiscibility Phenomena in Ferrous-Oxide/Sodium-Phosphate Slags. W. Oelsen and H. Wiemer. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1942, vol. 24, No. 13, pp. 167-210). This paper reports a continuation of an earlier investigation of slags by W. Oelsen and H. Maetz (*see* Iron and Steel Institute Translation No. 156) and it

covers $\text{FeO-Na}_2\text{O-P}_2\text{O}_5$ slags produced in iron crucibles with and without sodium fluoride and sodium chloride as fluxes. There was a wide miscibility gap in the $\text{FeO-Na}_2\text{O-P}_2\text{O}_5$ system in the $\text{FeO-Na}_2\text{O-3FeO.P}_2\text{O}_5\text{-3Na}_2\text{O.P}_2\text{O}_5$ region in spite of the fact that the boundary systems $\text{FeO-Na}_2\text{O}$, $\text{Na}_2\text{O-P}_2\text{O}_5$ and $\text{FeO-P}_2\text{O}_5$ were completely miscible in this range. The upper layer of slag consisted mainly of the mixed orthophosphates of iron and sodium with the composition $p\text{FeO}-(3n-p)\text{Na}_2\text{O-nP}_2\text{O}_5$ in which some surplus FeO was dissolved. The lower layer consisted almost entirely of FeO with a small amount of Fe_2O_3 and only a little P_2O_5 and Na_2O .

If sodium oxide is supplied to a composite slag consisting of an upper layer of calcium orthophosphate and a lower layer of ferrous oxide, most of the calcium in the upper layer will be replaced by sodium, and the lime which is formed will pass into the lower layer. It is thus possible to convert the calcium salts into sodium salts and at the same time to separate the reaction products in the melt. The experimental results prove that the oxides of iron, manganese, and chromium can be separated from the phosphorus pentoxide and a water-soluble sodium phosphate can be produced. The immiscibility phenomena which were noted at 1400°C . in iron crucibles also occurred at 1600°C . in the presence of molten iron. It is stressed that much better dephosphorisation and removal of sulphur from the molten iron are achieved with sodium oxide than with lime and the slag is at the same time left with a high phosphorus-pentoxide content.

The Melting Point of Manganese and Iron Ores. J. J. Howard. (Eastern States Blast Furnace and Coke Oven Association: Blast Furnace and Steel Plant, 1945, vol. 33, Aug., pp. 971-972). Determinations were made of the melting point of ten manganese ores from various parts of the world and of fourteen United States iron ores. In the former case the results varied between 2690° and 2930°F ., and in the latter between 2260° and 2845°F .

The Relationship between the Production of Iron Powders and the Properties of the Compacts. W. Dawihl and U. Schmidt. (Iron and Steel Institute, 1945, Translation Series, No. 257). An English translation is presented of a paper which appeared in *Stahl und Eisen*, 1945, vol. 65, Jan. 4, pp. 9-14 (see *Journ. I. and S.I.*, 1945, No. I., p. 121 A).

FOUNDRY PRACTICE

(Continued from pp. 159 A-160 A)

Melting and Casting of Grey Cast Iron. B. Stewart. (Australian Institute of Metals: Australasian Engineer Science Sheet, 1945, Aug. 7, pp. 4-14). After briefly describing the single-line tuyere cupola, the balanced-blast cupola and the hot-blast cupola, a comprehensive account of the physical and chemical aspects of cupola control and of casting is given.

Pearlitic Rim in Malleable Iron. J. E. Rehder. (Canadian Metals and Metallurgical Industries, 1945, vol. 8, Aug., pp. 29-31, 45). A theory is offered for the cause of the pearlitic rim often found at or just under the surface of malleable iron castings. The same thing occurs in the welding and subsequent re-annealing of malleable iron castings, where areas of cementite remaining in the weld area after re-annealing can be explained by the partial oxidation of silicon in the filler metal during welding. Badly oxidized heats of white cast iron which do not respond satisfactorily to normal annealing, although apparently of normal composition, can be explained by the same general theory.

Malleable Iron Control. M. E. McKinney. (American Foundryman, 1945, vol. 7, June, pp. 31-37). Methods of controlling the production of malleable iron castings are described. These include the calculation of the charge from the average of the analyses of the heats during the previous six days and the adjustment of the annealing furnace from information obtained from studies of the cementite and pearlite in prepared sections and by bend and hardness tests.

Continuous Methods in Cast-Steel Bomb Production. (Machinery, 1945, vol. 67, Nov. 1, pp. 477-483). Particulars are given of the layout of a foundry for producing 30,000 500-lb. cast steel bomb cases per month. The melting equipment consisted of four cupolas producing 20 tons/hr., two 12½-ton rotary preheating and mixing furnaces, and four side-blown acid converters. A high degree of mechanization was incorporated.

The Cumulative Curve for Foundry Sand Control. R. E. Morey and H. F. Taylor. (Foundry, 1945, vol. 73, Aug., pp. 98-101, 250-264). The A.F.A. (American Foundrymen's Association) method of determining and specifying sand fineness is criticized and the method of constructing and using "cumulative" curves is described and discussed. In plotting these curves the abscissæ represent particle sizes and the ordinates represent the percentages of material retained. To find the percentage of material coarser than a particular sieve, the amounts retained on that sieve and on all the coarser sieves must be added together, hence the term "cumulative curve."

Elevated Temperature Tests in Sand Control. A. Satz. (American Foundryman, 1945, vol. 7, June, pp. 55-59). A method of controlling the quality of foundry sand is described; it is based on the results of a compression-strength test at 2000° F. The application of this method of control reduced the number of rejected castings.

The Hot-Strength Characteristics of Moulding Sands. W. Davies and W. J. Rees. (Iron and Steel Institute, 1946, this Journal, Section I.). This paper summarizes the results so far obtained in the research which is in progress at Sheffield University on the hot-strength characteristics of moulding sands. A description of the apparatus employed is given. Attention has so far been directed towards the differences between the hot-strength characteristics of the various clay bonds in relation to their mineralogical constitution. All the bonds so examined show a gradual increase in strength with rise of temperature. After a maximum strength is reached, the strength decreases rapidly. This peak hot-strength is attained at a temperature of 900-1000° C. for clays having the silica-gibbsite-silica structure, *e.g.*, montmorillonite or secondary mica, and at temperatures of more than 1150° C. for clays having the silica-gibbsite, *i.e.*, kaolinite, structure.

Effective Shrink-Bob Risers. H. C. Winte and T. Barlow. (Foundry, 1945, vol. 73, Aug., pp. 82-86, 220-224). The authors believe that most cases of shrinkage cavities in grey iron castings are due to the faulty design of risers or to the gate being in the wrong position. They describe the "shrink-bob" riser which is almost cylindrical in shape, the diameter increasing slightly from top to bottom, and illustrate several examples of its use. In the system advocated, the sprue leads into the riser and the gate is always made in the side of the riser some distance above the bottom so that the correct proportion between the liquid metal in the riser and in the casting is maintained.

Moulding Large Cast Iron Crankshafts. G. Johnstone. (Foundry, 1945, vol. 73, Sept., pp. 89, 232-234). The advantages and disadvantages of various methods of casting large crankshafts are discussed, and advice on moulding is presented.

Precision Founding. F. Dittmar. (Iron Age, 1945, vol. 156, July 12, pp. 46-49; July 19, pp. 62-64, 138; July 26, pp. 70-73; Aug. 2, pp. 51-

57; Aug. 9, pp. 67-73; Aug. 16, pp. 70-74; Aug. 23, pp. 74-81). Several methods of precision casting are described. In Parts I. and II. the preparation of a glue mould for making trial plaster patterns is dealt with; the casting in this case being a ring 3 in. in outside dia. with a rim $\frac{1}{4}$ in. thick with a 1 in. face. The corners had to be sharp and the dimensions accurate within ± 0.02 in. In Parts III. and IV. the preparation of the plaster from which the trial moulds were made and of plaster moulds themselves is described. Details of the preparation of the matrix of treated reclaimed rubber and of Wood's metal or other alloy with a very low melting point are given in Part V. In Part VI. the making of wax patterns and carved plaster patterns is described. Part VII. deals with the practice of blowing nitrogen through molten aluminium to remove impurities.

Continuous Casting. L. H. Day. (Metal Treatment, 1945, vol. 12, Autumn Issue, pp. 193-199). The continuous-casting process developed by J. M. Merle is described. In this method molten metal is released in oblique streams from the bottom of a suitable container on to a rapidly rotating disc. The metal loses its latent heat by contact with the disc and is whirled round in a kind of spiral to be flung off at the periphery of the disc in atomised particles. These particles fly through a circular slit in their path of travel and build up in a mould which surrounds the device. Details of machines for continuously producing strip, sheet and bar, both plain and composite, are also given. Ferrous and non-ferrous metals as well as alloy steels have been successfully cast in these machines.

Mechanizing the Small Jobbing Foundry. W. S. Thomas. (Foundry, 1945, vol. 73, Aug., pp. 109-110, 168-172). The lay-out of a modern grey iron foundry producing about 15 tons of light castings per day, incorporating a sand reclamation system, is described.

Foundry Research—at American Brake Shoe Co. W. G. Gude. (Foundry, 1945, vol. 73, Sept., pp. 94-97, 196-198). An experimental foundry is described. It was set up in order to improve foundry processes, and to develop new products. Modern full-size equipment is provided to handle operations such as sand preparation, moulding, core baking, melting, shaking out, casting, cleaning, and heat-treatment. Six electric furnaces including a 1000-lb. arc-type furnace as well as numerous cranes, and centrifugal casting machines are among the equipment of the foundry which can produce castings weighing up to 1 ton.

New Malleable Foundry is Modern. (Foundry, 1945, vol. 73, Sept., pp. 84-88, 226-228). A well-illustrated account of the layout and equipment of a large American foundry for malleable castings is presented.

Mechanization of Iron and Steel Foundries. J. W. Sardon. (Foundry, 1945, vol. 73, Sept., pp. 98-101, 191-194). A description is given of the layout of an English foundry mechanized during the war. The three main advantages are: Increased production without increased floor area or labour, better working conditions, since operations which produce heat, dust, or fumes can be isolated, and the standardization of operations, thus enabling better control to be exercised.

The Modern Specialised Foundry. W. Jones. (Institute of British Foundrymen: Foundry Trade Journal, 1945, vol. 77, Oct. 18, pp. 135-138, 142). A description is given of a foundry built in Great Britain during the war; it represents a good example of careful planning in which care was taken to ensure that the foundry was a clean, healthy, well-lighted and efficient unit of production.

Solidification of Metals. H. A. Schwartz. (Foundry, 1945, vol. 73, Sept., pp. 107-108, 210-218). The basic principles involved in the transformation of metals from the liquid to the solid state are discussed. The need for employing physicists in foundry work to substitute technology for

craftsmanship is emphasized. The contraction of steel freezing under restraint and similar problems are discussed.

PRODUCTION OF STEEL

(Continued from pp. 160 A-162 A)

Some Developments in Ferrous Metallurgy. C. Sykes. (Journal of the Institution of Civil Engineers, 1945, vol. 24, Oct., pp. 315-348). The author describes some developments in ferrous metallurgical products and in experimental technique. The following subjects are dealt with: Steel melting, segregation, tests for cleanliness and freedom from defects, transformation rates, hardenability, conservation of alloying elements, welding, corrosion and scale resistance, creep and design data, improved creep-resisting materials, high permeability of magnetic materials, and permanent magnets. A bibliography of 32 papers is given.

Deoxidation with Manganese in the Basic Bessemer Converter. H. Wentrup and O. Reif. (Iron and Steel Institute, 1945, Translation Series, No. 256). An English translation is presented of a paper which appeared in *Archiv für das Eisenhüttenwesen*, 1945, vol. 18, Jan.-Feb., pp. 131-138 (see p. 35 A).

Effect of Ingot Delivery Time as a Factor in Quality of Bessemer Steel. H. C. Dunkle. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1878: Metals Technology, 1945, vol. 12, Aug.). The influence of the times elapsing between pouring ingots of Bessemer steel and charging the ingots in the soaking pits, and between stripping the ingots and charging the soaking pits, on the quality of the rolled steel was investigated. The effect of the former period is much more important than that of the latter. The best quality high-sulphur machining steels are obtained when the ingot delivery time is the shortest. The number of rejections increases to a maximum and then declines as this time increases; it is probable that this maximum point corresponds to the time necessary for complete solidification of the ingot.

A Completely Automatic Control of Open-Hearth Reversal. R. M. Larson and W. E. Shenk. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1830: Metals Technology, 1945, vol. 12, June). A fully automatic method of controlling the reversal of gases for open-hearth furnace operation is described in detail. It is activated by radiation pyrometers sighted on the top layer of the checker brickwork.

Cleaning Open Hearth Checkers by Vacuum. A. F. Franz. (Iron and Steel Engineer, 1945, vol. 22, Sept., pp. 108-110). A brief description is given of a vacuum system for the removal of flue dust from open-hearth checker chambers. It consists of a receiving vessel 6 ft. high and 3 ft. in dia. with a cyclone attached, a steam exhauster which puts the vessel under vacuum, standard steel pipes with cast-iron fittings, about 60 ft. of flexible hose, and a receiving nozzle. With a 4-in. pipe line the system can collect 10 tons of dust per hr. A saving of 60% of the man-hours for checker cleaning has been achieved since this system was installed at one steelworks.

A Rapid Laboratory Method for Estimating the Basicity of Open-Hearth Slags. W. O. Philbrook, A. H. Jolly, jun., and T. R. Henry. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1862: Metals Technology, 1945, vol. 12, Aug.). A method of determining the composition of open-hearth slag is described. It consists of measuring the slight alkalinity of a suspension of the powdered slag in

water by means of a glass-electrode pH meter (*see* Journ. I. and S.I., 1945, No. I., p. 47 A).

Application of pH Slag-Basicity Measurements to Basic Open-Hearth Phosphorus Control. M. Tenenbaum and C. C. Brown. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1863: Metals Technology, 1945, vol. 12, Aug.). The application of slag-basicity measurements obtained by the method referred to in the preceding abstract to the control of basic open-hearth furnaces is discussed. The method gives an effective indication of the ability of the slag to retain phosphorus. The screen size of the slag sample is the principal physical factor affecting the pH reading. The "minus 80-mesh" fraction is a satisfactory particle size. Curves have been developed showing the effect of the basicity and oxidation of the slag on the final phosphorus content of the steel in the ladle for various types of steel; these demonstrate that for effective phosphorus control the slag composition must be adjusted according to the amount and type of the deoxidisers added to the furnace when finishing the heat.

The Mechanical Phase of Open Hearth Steel Manufacture. F. Sundblad. (Iron and Steel Engineer, 1945, vol. 22, Aug., pp. 51-56). A review is made of the changes in the type of steel scrap used by American steelmakers during the last 25 years and of developments in the methods of charging open-hearth furnaces. The effects of the large quantities of scrap now lying on the Continent of Europe, a large proportion of which is the property of the United States Government, are discussed and a proposal for its disposal is made.

The Effect of Phosphorus on the Metallurgy and Economics of the Basic Duplex Process. H. Buchholtz and K. Debuch. (Stahl und Eisen, 1943, vol. 63, Oct. 28, pp. 777-783). Tests are described in which various methods were employed to produce Bessemer metal with a wide range of phosphorus contents for finishing in the basic open-hearth furnace. With extra blowing and lime additions such that the Bessemer metal contained 0.04% of phosphorus, the loss of iron was 7%, and was about twice as much as the loss when the product contained 0.08-0.10% of phosphorus. A content of less than 0.05% of phosphorus was obtained by after-blowing with additions of a mixture of lime and mill-scale; in this case the total loss of iron was reduced to 2%. The advantages which are gained in the open-hearth process by charging with low-phosphorus metal depend on the quality of the steel to be produced. Taking the duplex process as a whole, the optimum phosphorus content of the Bessemer metal for an end-product of mild steel with not more than 0.05% of phosphorus was found to be 0.09-0.10%. The most economical method of producing mild steel proved also to be best from the metallurgical point of view.

The Development of Electric Furnaces for Steelmaking. N. F. Dufty. (British Steelmaker, 1945, vol. 11, Oct., pp. 442-445). The history of the development of electric furnaces for steelmaking is reviewed.

The Reduction of Silica by Liquid Steel. W. Geller. (Archiv für das Eisenhüttenwesen, 1942, vol. 15, May, pp. 479-490). The theory of the reactions between molten steel and a silica hearth, in particular the factors affecting the reduction of silica, are examined. Experiments are reported with 50-60 kg. melts in a 92%-silica crucible heated in a coreless induction furnace in which white sand containing different amounts of carbon was put on the surface of the molten metal in three melts and glass slag was added in a fourth melt. The silica was reduced more rapidly under sand than under the glass slag and the sand protected the melt from oxidation by the air just as effectively as the glass slag. The optimum temperature for the reduction was about 1650° C. It was found that over-oxidation of the metal when producing mild steel in a silica-lined furnace could be

prevented by adjusting the carbon content of the charged materials so that, on completion of the reduction of the silica, sufficient silicon was left to kill the steel. Diagrams showing C-Si-O equilibria at different temperatures are shown. The results are applicable to melts in coreless induction furnaces, but it seems probable that an open-hearth furnace slag could be replaced to a considerable extent by a layer of sand. Apart from the acceleration in the reduction of the silica, the danger of renewed oxidation by the slag when teeming the steel would not arise.

Mineralogical Observations on Some Basic Open-Hearth Slags. S. O. Agrell. (Iron and Steel Institute, 1946, this Journal, Section I.). The principal phases that may occur in basic open-hearth tapping slags are lime, magnesio-wüstite, nagelschmidtite, di- or tri-calcium silicate and apatite, with smaller amounts of monticellite, merwinite, and calcium ferrites. In the melting-down stage monticellite, or more rarely merwinite and wüstite-magnetite solid solutions, predominate in those slags to which no fluorspar has been added; in addition a phase is also recorded whose properties most closely resemble those of steadite. The chemical composition, optical properties, and mutual relations of the above phases occurring in a number of slags are given, and the variations of phase assemblages from two casts are described in detail.

The variation of phase assemblages of these and other slags is summarized by plotting the different assemblages on the ternary diagram $\text{CaO}-\text{P}_2\text{O}_5-\text{SiO}_2$, and it is shown that they fall into definite fields on this diagram. With further study of the phase assemblages of slags the chemical compositions of which are known, this diagram could be amplified so that the phase assemblages of basic slags could be predicted from their chemical compositions.

The Relations between Iron Containing Manganese and Slags Consisting Almost Entirely of Manganous and Ferrous Oxides. F. Körber and W. Oelsen. (Iron and Steel Institute, 1945, Translation Series, No. 254). An English translation is presented of a paper which appeared in *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1932, vol. 14, No. 13, pp. 181-204 (*see* Journ. I. and S.I., 1933, No. I., p. 575).

Furnace Charging Equipment. (British Engineering, 1945, vol. 28, Sept.-Oct., p. 173). A 30-ton overhead travelling crane for top-charging large electric furnaces and a box charging machine for open-hearth furnaces are described and illustrated.

Hook, Tong, and Grab Auxiliaries in Modern Steelworks. A. G. Arend. (British Steelmaker, 1945, vol. 11, Oct., pp. 446-449). Modern designs of crane hooks, ingot tongs, and grabs for steelworks are discussed.

Water Supply. C. D. Foight. (Iron and Steel Engineer, 1945, vol. 22, Sept., pp. 57-63). The water requirements for different parts of a steelworks are discussed with notes on methods of calculating flow through nozzles of various sizes and the minimum velocities necessary in different supply mains.

ROLLING-MILL PRACTICE

(Continued from p. 163 A)

Hot-Rolling Tests on Steel Coated on One and on Both Sides. A. Pomp and W. Lueg. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1942, vol. 24, No. 9, pp. 123-137). Hot-rolling tests in the 700-1200°C. range were carried out and the roll pressure, increase in width and speed gain were determined on 30-mm. bars of the following materials: (1) Mild steel (carbon 0.09%); (2) steel coated with copper on

both sides to thicknesses of 5%, 10% and 20%; (3) steel coated on both sides with 18/8 stainless steel; (4) copper; (5) stainless steel; (6) steel coated on one side with copper 6 mm. thick; and (7) steel coated on one side with stainless steel 6 mm. thick. The roll pressures differed greatly for the uncoated materials whilst the increase in width and the speed gain were only slightly affected by the material. With the composite materials the increase in width and speed gain were not measured because of the non-uniform flow of the two components. The roll pressure for the composite materials could be determined from the pressures for the separate components taken in the proportion of their thickness to the total thickness.

Rolling Pressure and Work in the Cold-Rolling of Metals. E. Siebel and W. Pomp. (Iron and Steel Institute, 1945, Translation Series, No. 252). An English translation is presented of a paper which appeared in *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1929, vol. 11, No. 4, pp. 73-85 (*see Journ. I. and S.I.*, 1929, No. I., p. 724).

Storage and Handling of Lubricants. L. E. Lovitt. (Iron and Steel Engineer, 1945, vol. 22, Sept., pp. 52-53, 56). Means of storing oils are described and methods of removing sludge, oxides and water from used oil are discussed.

Organization of a Lubrication Department. C. A. Bailey. (Iron and Steel Engineer, 1945, vol. 22, Sept., pp. 54-56). The duties of a lubrication engineer and the organization of labour to ensure the application of the proper lubricant in the correct manner at the right time-intervals are discussed.

Lubricants in Maintenance. V. A. Smith. (Iron and Steel Engineer, 1945, vol. 22, Sept., pp. 85-86). Recommendations on the organization of a lubrication department with its own supervisor are made.

Shaft Currents May Cause Bearing Failure. D. B. Hoover. (Iron and Steel Engineer, 1945, vol. 22, Sept., pp. 72-74, 78). Currents are often set up in the shafts of motors and generators and, if these cross the oil film in the bearing, pitting and excessive wear of the bearing shell are caused. Methods of eliminating this trouble are described.

Simplified Lubrication. J. G. O'Neill, jun. (Steel, 1945, vol. 117, Oct., pp. 118, 124). Tables are presented showing the types of oil and their properties which are recommended for various purposes in iron and steel works.

West Coast Steel Mill. G. E. Stedman. (Steel, 1945, vol. 117, July 2, pp. 108-110, 158; July 16, pp. 134-136, 174-178; Aug. 6, pp. 130-133; 159-164). An illustrated description is given of the rod and wire mill of the Columbia Steel Company, Pittsburgh, California, where the plant consists of a large gas-fired billet reheating furnace and twenty-one mill stands.

Vertical Precision Mill. M. C. McConnell. (Iron and Steel, 1945, vol. 18, Oct., p. 454). A description is given of a new type of rolling mill stand for rolling rounds from $\frac{3}{8}$ in. to $1\frac{1}{2}$ in. in dia. with very close tolerances. The stand has two vertical rolls 12 in. in dia. by 15 in. long which are driven by a 100-h.p. D.C. motor.

Modernizes Barmaking Facilities. (Steel, 1945, vol. 117, Oct. 1, pp. 110-111, 145-146). A new 18-stand 10-in. bar mill for the Bethlehem Steel Company which will have a delivery speed of 2400 ft./min. is briefly described.

The Hot-Rolling of Wire and Steel Strip. H. Wiesecke. (Stahl und Eisen, 1943, vol. 63, Dec. 30, pp. 953-961). The development in Germany and other countries of mills for the hot-rolling of wire and square rods from 5 to 13 mm. thick, and of strip from 8 to 30 mm. wide up to 8 mm. thick, is discussed with particular reference to the layout of the mill trains. Modern reheating furnaces for these mills are also dealt with.

Electrical Maintenance. J. Stewart. (Iron and Steel Engineer, 1945, vol. 22, Sept., pp. 82-84). The preventative maintenance of electric motors, transformers, controllers, and cables is discussed.

Protection for A.C. and D.C. Motors. C. E. Homer. (Iron and Steel Engineer, 1945, vol. 22, Sept., pp. 70-71). Recommendations are made for the maintenance of thermal overload relays of three types, namely, the bimetal strip, the solder pot or solder film, and the magnetic-alloy types.

HEAT-TREATMENT

(Continued from pp. 164 A-165 A)

Hard Steel Surfaces. D. Taylor. (Automobile Engineer, 1945, vol. 35, Oct., pp. 401-404). The advantages and limitations of solid-, liquid-, and gas-carburizing, nitriding, flame-hardening and induction hardening are discussed.

Wide Range of Furnace Types Broadens Scope of Lindberg Steel Treating Work. (Industrial Heating, 1945, vol. 12, July, pp. 1216-1227). A description is given of the heat-treatment department of the Lindberg Steel Treating Company, Chicago, where a wide variety of work, including hardening with gaseous, liquid, and solid media, is undertaken.

Modern Heat Treating Practice. A. P. Seasholtz. (Steel, 1945, vol. 117, Sept. 3, pp. 120-122, 176-182; Sept. 10, pp. 114-116, 172-189; Sept. 17, pp. 132-137, 164-170; Sept. 23, pp. 153-157, 176-180; Oct. 1, pp. 126-130). The theory and practice of heat-treatment are comprehensively reviewed.

Notable Electric Heat-Treatment Furnaces. (Metal Treatment, 1945, vol. 12, Autumn Issue, pp. 171-176, 182). Recent advances in the design of electrically heated furnaces for heat-treating ferrous and non-ferrous metals are described and several modern installations are illustrated.

Electric Furnaces. (British Engineering, 1945, vol. 28, Sept.-Oct., pp. 191-196). A wide variety of designs of electric furnaces for melting and heat-treating ferrous and non-ferrous metals is described.

Recent Developments in Electric Furnaces. V. O. Cutts. (Fuel Economy Review, 1945, vol. 24, pp. 47-51). A number of modern batch and continuous furnace installations for heat-treatment are described and illustrated.

Practical Heat Treatment and Annealing of Alloy Steel Bars. Q. C. McMillan. (Metal Treatment, 1945, vol. 12, Autumn Issue, pp. 177-182). A modern heat-treatment plant for alloy steel bars is described; it comprises two electric furnaces, two gas-fired furnaces and quenching tanks all in line. The planning of the sequence of charges so as to maintain maximum output with the greatest efficiency and the use of an "efficiency coefficient" are discussed.

Modern Heat-Treatment Equipment. (Iron and Coal Trades Review, 1945, vol. 151, Oct. 26, pp. 627-632). An illustrated description is given of the new heat-treatment plant at the works of the Scottish Stamping & Engineering Company, Limited. It consists of twelve furnaces, operating in four units of three chambers, each 6 ft. wide \times 7 ft. 1½ in. long. They are fired with gas generated from coke breeze in a producer 10 ft. in dia. The plant is served by two 5-ton overhead cranes and two travelling revolving charging machines on a rail track between the bank of furnaces and the quenching tanks.

Heat Treating Tank Parts in Buick Plant. (Industrial Heating, 1945, vol. 12, Aug., pp. 1292-1316). An illustrated description is given of the heat-

treatment plant at one of the works of the General Motors Corporation for the gas-carburizing, hardening and tempering of tank parts, with special reference to gears.

The Purnell Process for Heat Treating Steel. C. G. Purnell and H. M. Pfahl. (Industrial Heating, 1945, vol. 12, July, pp. 1116-1130). The Purnell heat-treating system for small parts is described (*see abstract* entitled "Improved Quenching," p. 113 A).

Liquid Carburizing of Transmission Gears at the Cleveland Tractor Works. W. A. Silliman. (Industrial Heating, 1945, vol. 12, Sept., pp. 1504-1510, 1516). The salt-bath case-hardening plant and process for hardening tractor gears and shafts at the works of the Cleveland Tractor Company, Ohio, are described.

Electrode Salt Baths. (Automobile Engineer, 1945, vol. 35, Sept., pp. 376-378). A description is given of recent developments in small electrically-heated salt-bath furnaces for heat-treating tools.

The Necessity for the Closer Control of the Effect of the Gas Atmosphere in Industrial Furnaces on the Fuel and the Charge. J. A. Hedvall. (Transactions of Chalmers University of Technology (Gothenburg), 1944, No. 30). The effect of the products of combustion in industrial furnaces on the physical-chemical activity of certain oxides is discussed and some experiments with the systems $\text{CaO} + \text{SiO}_2$, $\text{CaO} + \text{Al}_2\text{O}_3$, and $\text{CaO} + \text{Fe}_2\text{O}_3$, using the gases oxygen, nitrogen, air, sulphur dioxide, sulphur dioxide plus oxygen, and sulphur trioxide, are described. It is shown that the effects vary considerably with the preheating time and temperature, and that a maximum effect is obtained at temperatures where the mobility of the lattice particles is not too great. In systems where the reactivity of a solid is increased by preheating it in a gas, it is possible to distinguish between the effect caused by changes in the surface dimensions and that of the distortion of the lattice by the dissolved gas.

Carburizing and Nitriding. A. H. Allen. (Steel, 1945, vol. 117, Sept. 24, pp. 118, 166). A muffle furnace for the continuous carburizing or nitriding of thin steel parts such as thrust washers and retainer rings is described. Using a special atmosphere at 1425° F. it is possible to obtain "file-hard" surfaces.

Surface Hardening by Medium-Frequency Induction Heating. G. Seulen and H. Voss. (Stahl und Eisen, 1943, vol. 63, Dec. 23, pp. 929-935; Dec. 30, pp. 962-965). The electrical and mechanical requirements of plant for the induction hardening of bars and machine parts using frequencies in the 600-10,000/sec. range are described. The conditions for hardening both stationary and moving parts are also dealt with. Determinations of the temperature distribution across sections of various parts were made and the effects of time and current on the depth of hardness are shown by examples. Finally, the quality of steels suitable for induction hardening is discussed. (An English translation of this paper is published in Iron and Steel, 1945, vol. 18, Oct., pp. 445-453, 466).

Induction Heating of Small Parts. S. A. Covert. (Iron Age, 1945, vol. 156, Sept. 27, pp. 60-63). Examples of the application of induction heating to the surface hardening of small and thin-walled parts are described and data on the decrease in the depth of the heated layer with increasing frequency of the current are presented.

Uncommon Applications of High-Frequency Heating. E. D. Tillson. (Iron Age, 1945, vol. 156, Oct. 4, pp. 72-73, 158-160). The unusual applications of induction heating described in this paper include the heat-treatment of hair-pins, the heating of thin parts at positions where they are to be bent, and the heating of plastic patterns in moulds so that the material can be run out.

Wright Aeronautical Corp. Uses Large Battery of Nitriding Furnaces. J. A. Schneider. (Industrial Heating, 1945, vol. 12, July, pp. 1150-1152). A brief description is given of a nitriding plant consisting of 58 electrically heated bell-type furnaces for hardening aero-engine cylinders and gears.

Ammonia for Processing Metals. E. R. Woodward and R. J. Quinn. (Metals and Alloys, 1945, vol. 22, Aug., pp. 418-424). Descriptions are given of how ammonia and its derivatives can be applied to solve problems in the case-hardening, heat-treating, brazing, sintering, and welding of metals.

WELDING AND CUTTING

(Continued from pp. 165 A-166 A)

Arc Welding Tool Steel with Stainless Electrodes. H. W. Rushmer. (Australasian Engineer, 1945, Aug. 7, pp. 37-39, 81). The technique for welding high-speed tool steel tips to carbon steel shanks using stainless steel electrodes is described.

Shop Notes on Welding Stainless Steel. V. J. Shanahan. (Welding Journal, 1945, vol. 24, Aug., pp. 727-729). Practical advice on the welding of stainless steel is offered under the following headings: (1) Comparison of welding carbon steel and stainless steel; (2) effects of heat on stainless steel; (3) selection of the type of electrodes; (4) selection of size and quantity of electrodes; and (5) operating instructions.

Silver Brazing of Steel Parts. A. N. Setapen. (Steel, 1945, vol. 117, Sept. 24, pp. 112-115). The silver-soldering of steel is described and its advantages discussed.

Steel Plant Welding. W. K. Simon. (Iron and Steel Engineer, 1945, vol. 22, Sept., pp. 92-95). Examples are given of the construction by welding of various items of rolling-mill equipment, parts of ingot stripping cranes, and stove checker supports.

Steel Welding Costs and Electrode Selection. O. T. Barnett. (Metals and Alloys, 1945, vol. 22, Aug., pp. 408-414). Methods of testing the efficiency of welding electrodes and of determining welding costs are reviewed and explained.

Effect of the Melting Process and Heat-Treatment on the Weld-Crack-Sensitivity and the Weld-Strength of Thin Steel Sheets Containing about 1% of Manganese. W. Eilender, H. Arend and I. Mircea. (Stahl und Eisen, 1943, vol. 63, Oct. 28, pp. 784-787). The crack-sensitivity, the increase in hardness, and the strength of welds in 1-mm. sheets of 18 steels with carbon 0.15% to 0.44% and manganese 0.7% to 1.0% were investigated, with special reference to the effects of the melting process (whether superheated or not), the McQuaid-Ehn grain size and the heat-treatment. With steels of equal carbon contents, the normally-melted fine-grained quality had the lowest crack-sensitivity, but with steels having the same strength of welded joint the crack-sensitivity of the coarse-grained qualities was less than that of the fine-grained qualities.

Metallurgical Factors of Underbead Cracking. S. L. Hoyt, C. E. Sims and H. M. Banta. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1847: Metals Technology, 1945, vol. 12, June). Steel manufacture and processing methods are discussed with a view to showing how their control assists in reducing the risk of cracks in welds, particularly those in the parent metal under the bead. A new method of rating the cracking tendency is suggested and the results of tests are related to the composition, structure, method of manufacture, and heat-treatment.

Stress Relief of Weldments for Machining Stability—Part II. J. R. Stitt. (Ohio State University, 1945, Sept., Engineering Experiment Station Bulletin No. 123). The investigation of the effects of thermal and mechanical stress-relieving treatments previously reported (*see* p. 60 A) has been extended to cover a 0.3%-carbon steel and a chromium-nickel-molybdenum steel.

MACHINING

(Continued from p. 115 A)

The Machining of Metals. J. S. Anderson. (Australian Institute of Metals: Australasian Engineer, Science Sheet, 1945, Aug. 7, pp. 16-23, 32). The following factors affecting machinability are discussed: (1) The physical properties, chemical composition, structure, and degree of hot or cold work of the metal being cut; (2) the temperature; (3) the composition, shape and condition of the tool; (4) the cutting fluid; (5) the cutting speed and feed.

Metallographic Definition of Plastic Deformations in some Machining Chips. A. Portevin and P. Bastien. (Revue de Métallurgie, Mémoires, 1941, vol. 38, July, pp. 165-184). After considering the criteria and factors upon which the machinability of metals depends, the authors concentrate on the examination of chips produced by the machining of various carbon and special steels. The investigation comprises the visual inspection of surfaces, followed by the macrographic and micrographic examination of three perpendicular sections of the chips, and by hardness tests. In conclusion the authors state that the metallographic methods are perfectly suitable for the investigation of plastic deformations in chips caused by machining, and they permit the tool shape, the cutting speed and the volume of metal removed in unit of time to be defined, thus allowing the optimum conditions of chip formation to be assessed.

Production Machining of Steel. (Mechanical World, 1945, vol. 118, Nov. 2, pp. 485-487). Specifying steel for the production machining of many similar parts is discussed and a method of establishing the optimum machining conditions is described.

A Guide to the Machining and Manipulation of Stainless Steels. W. F. Walker. (Institute of Production Engineers: Australasian Engineer, Science Sheet, 1945, Sept. 7, pp. 17-25). Methods of machining, forging, pressing, joining, and polishing stainless steels are described.

Ultra-Fine Surfaces on Metals. K. Rose. (Metals and Alloys, 1945, vol. 22, July, pp. 70-75). Comparisons are made between the surfaces obtained by rough-grinding, fine-grinding, honing, lapping and super-finishing. Methods of measuring surface finish and the degrees of smoothness specified for bearings, cylinder bores, crank pins, and gear teeth in aircraft engines are discussed.

Some Production and Maintenance Instruments. C. S. Cassels. (Iron and Steel Engineer, 1945, vol. 22, Sept., pp. 97-100). Illustrated descriptions are given of the following instruments: (1) A profilometer in which the trace of a diamond point across a metal surface is measured electrically; (2) a pneumatic comparator for checking the flatness of a part by measuring the change in pressure of air jets directed against it; (3) a gauge for measuring the moisture content of wood; and (4) a "strobotac" which is a combination of a stroboscope and a tachometer.

PROPERTIES AND TESTS

(Continued from pp. 167 A-172 A).

Free-Machining Open-Hearth Bar Steels. (Metals and Alloys, 1945, vol. 22, Aug., pp. 425-428). The analyses, properties, and machinability ratings of a number of steels on the official list of free-cutting open-hearth steels drawn up by the American Iron and Steel Institute are presented and discussed.

The Corrected Saturation Factor and Its Application in Practice. P. Tobias and G. Brinkmann. (Giesserei, 1942, vol. 29, Oct. 2, pp. 340-341). The factor expressing the degree of carbon saturation in grey cast iron has been amended by the authors to

$$\frac{\%C}{4.23 - 0.312 \text{ Si} - 0.33 \text{ P} + 0.066 \text{ Mn}}$$

(see Journ. I. and S.I., 1943, No. I., p. 135 A). An example of the practical application of this formula to calculate the chemical composition of a grey iron which will have a required tensile strength for a given sized bar is presented.

The Effect of After-Treatment on the Properties of Steel Wire. W. Pügel. (Iron and Steel Institute, 1945, Translation Series, No. 253). An English translation is presented of a paper which appeared in Stahl und Eisen, 1942, vol. 62, Oct. 8, pp. 853-858; Oct. 15, pp. 876-879 (see Journ. I. and S.I., 1943, No. I., p. 59 A).

Tensile Deformation. J. H. Hollomon. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1879: Metals Technology, 1945, vol. 12, June). The effects of tensile strain and changes in the metallurgical structure of metals on the stress required for plastic flow are discussed. A simple method of constructing approximate stress-strain curves and a new relation between the yield point and the fracture strength of tempered martensitic steels are suggested.

The Calculation of Stress from X-Ray Elongation Measurements. H. Neerfeld. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1942, vol. 24, No. 6, pp. 61-70). Comparisons are made between measurements of elastic and plastic elongation obtained by mechanical and X-ray methods.

Single-Strip Compression Test for Sheet Materials. H. LaTour and D. S. Wolford. (American Society for Testing Materials, 1945, Preprint No. 30). A new jig for testing steel sheet from 0.01 to 0.10 in. in thickness in compression using a flat single-strip specimen is described. Flat guides provide continuous support to the specimen and prevent lateral buckling. The results obtained on a number of specimens are presented and discussed.

Low-Temperature Behaviour of Ferritic Steels. (Iron Age, 1945, vol. 156, Oct. 4, pp. 69-71, 154-158). The results of low-temperature impact tests carried out at the University of Kentucky on ferritic steels are discussed. Fine-grained ferritic steels have greater impact strength at low temperature than coarse-grained steels, and any heat-treatment which tends to coarsen the grain is detrimental.

The Relationship between the Nature of the Fracture and the Notched-Bar Toughness of Some Heat-Treated Steels. A. Krisch and W. Puzicha. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1942, vol. 24, No. 14, pp. 211-218). The results of notched-bar impact tests on ten heat-treated high-carbon and low-alloy steels are presented

Specimens of the steels were also fractured and these were classified by the R.D.L.I. method (*Reichsverband der Deutschen Luftfahrt-Industrie*). The impact values and the fracture ratings were compared by statistical methods but no relationship could be established.

Attempts to Determine the Damage and Increase in Strength in the Sphere of "Time-Resistance." E. Siebel and G. Stähli. (*Archiv für das Eisenhüttenwesen*, 1942, vol. 15, May, pp. 519-527). The impact test as a means of studying the "time-resistance" (*Zeitfestigkeit*) of steels, in particular the point at which damage begins, is discussed. Time-resistance has been defined as the capacity of a material to withstand a limited number of stress reversals above the fatigue strength until fracture supervenes (*see* Journ. I. and S.I., 1938, No. II., p. 35 A). Experiments are also described in which notched specimens of two carbon steels, a chromium-molybdenum steel and duralumin, were first subjected to stress reversals in a Wöhler machine and then fractured in a Charpy impact machine with the axis of the specimen in line with the direction of the blow. The effect of a limited bending-fatigue treatment was to increase the toughness as measured by the blow required to cause fracture, the amount of the increase being greatest with a large number of reversals at low stress. It is probable that the preliminary bending-fatigue treatment smooths out the non-uniform stresses in the structure from surface to core. Tests were also made in which the notch was carefully polished after the preliminary stressing and these confirmed the theory that the damage begins at the surface and is independent of the "homogenizing effect" which gradually extends over the whole of the section. The impact test provides an excellent method of obtaining data to construct damage curves.

Stress Distribution. E. S. Clark. (*Steel*, 1945, vol. 117, Sept. 24, pp. 116, 146). The methods of determining the distribution of stress in steel parts and structures are reviewed.

Magnetic Crack Detection. (*Metal Treatment*, 1945, vol. 12, Autumn Issue, pp. 146, 170). When a heavy alternating current from a transformer secondary as the magnetizing force is used in magnetic powder methods of crack detection it has been found that some components so tested have no residual magnetism. Hence doubt arises whether accepted articles are magnetized and free from cracks, or are cracked and free from magnetism. To resolve this doubt an instrument has been devised, and is described in this article, for the simultaneous application of the detecting agent and the magnetizing current.

Tension-Compression Fatigue Tests on Steel at High Temperatures and Their Evaluation by Different Methods. M. Hempel and H. Krug. (*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1942, vol. 24, No. 7, pp. 71-95). An abridged version of this and another paper by the same authors (*see* next abstract) has already appeared in *Archiv für das Eisenhüttenwesen*, 1943, vol. 16, Jan., pp. 261-268 (*see* Journ. I. and S.I., 1944, No. II., p. 88 A).

Effect of the Elastic Limit on the Bending Fatigue Strength of Steel. M. Hempel and H. Krug. (*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1942, vol. 24, No. 7, pp. 96-103). *See* preceding abstract.

The Bending Fatigue Strength of Case-Hardened and Nitrided Steels with Grinding Cracks. H. Staudinger. (*Zeitschrift des Vereines Deutscher Ingenieure*, 1944, vol. 88, Dec. 23, pp. 681-686). German low-alloy chromium and chromium-molybdenum steels in the case-hardened state were subjected to bending-fatigue tests to determine the reduction in fatigue strength caused by grinding cracks in the surface. The reduction was found to be about 33½%.

Increasing Fatigue Resistance by Shot Peening. (Machinery, 1945, vol. 67, Oct. 25, pp. 449-454). Illustrated descriptions are given of shot-peening machines which are used to throw shot from a centrifugal wheel revolving at high speed against parts such as hypoid gears, crankshafts, steering knuckles and springs used in aeroplane, tank, and automobile construction. The effect of the shot-peening is to leave the surface fibres of the part in compression and the inner fibres in tension, and thus to increase the resistance to fatigue.

The Effect of the Pretreatment and the Carbide Distribution on the Fracture and Depth of Hardness in Hypereutectoid Steels. B. D. Enlund and G. Sehlberg. (Jernkontorets Annaler, 1945, vol. 129, No. 10, pp. 571-576). (In Swedish). Specimens of three acid open-hearth steels containing 1.00-1.20% of carbon and two basic electric-furnace steels containing 1.32-1.38% of carbon and 0.5% of chromium were subjected to four treatments, namely, annealing, normalizing, quenching in oil, and quenching in water. They were then hardened and fractured. The fractures were compared using Jernkontoret's standard scale and the depths of hardness were measured. Micrographs of the structures obtained are shown. Fine-grained fractures were associated with shallow hardness.

The Hardness-Testing of Case-Hardening Steels. H. Voss. (Stahl und Eisen, 1943, vol. 63, Oct. 21, pp. 767-770). Three methods of determining the increase in the tensile strength of steel produced by case-hardening are described. These are: (1) By tensile tests; (2) by Brinell tests on the core of a fractured specimen; and (3) by preparing a disc specimen from the centre of a billet or bar, hardening it, and making Brinell tests across it. Tests were made by these methods on 150 case-hardening steels (carbon 0.15-0.23%, manganese 0.7-1.2%, chromium 0.9-1.4%, and molybdenum 0.2-0.3%) and the results are compared in tables and by curves.

The Applicability and Limitations of Microhardness-Testing. W. Bischof and B. Wenderott. (Archiv für das Eisenhüttenwesen, 1942, vol. 15, May, pp. 497-504). Comparisons are made between the results of hardness tests made with a Vickers instrument equipped for fine measurement, an automatic microhardness tester with photographic recording of the depth of the impressions, and a microhardness tester designed by E. M. H. Lips. Loads from 3 g. to 100 kg. were applied on soft iron, copper, aluminium and martensite. With the Vickers instrument the impression under load was larger than after removing the load owing to a certain amount of "spring-back" or recovery. The recovery was greater after light loads than after heavy ones. There was greater recovery with the martensite than with the softer materials tested. As the recovery in depth was greater than that measured along the diagonals, the impressions during and after the load were not geometrically similar. The calculation of hardness from the dimensions of impressions after removing the load was therefore subject to error. The depth of the Vickers impression did not decrease directly with the square root of the load but more rapidly than that. Directly comparable hardness values could only be obtained in a narrow range of loads; microhardness test results could not therefore be compared with the results obtained under ordinary loads. The decrease in the size of impressions measured with decreasing loads on etched specimens was probably caused by the friction between the indenter and the material, although the effect may have been masked by the work-hardening induced by grinding and polishing.

Factors Affecting Microhardness Measurements. E. B. Bergman. (Jernkontorets Annaler, 1945, vol. 129, No. 10, pp. 577-627). (In Swedish). The sources of error and limitations of microhardness testing are discussed

with a review of the literature and an account of some of the author's own work. The loading speed should be kept as constant as possible and a speed of 1 mm./min. is proposed. The duration of the test should be sufficient for static conditions to be attained. For some materials 15 sec. is sufficient, others require a slightly longer time. With the very best lens systems the limit of accuracy in measuring the diagonals is 0.3μ . When there is elastic recovery, depth measurements are unreliable but its effect on the length of the diagonals is of little importance.

Brinell Hardness Testing Machine. (Engineering, 1945, vol. 160, Nov. 9, p. 370). A new Brinell hardness testing machine suitable for tests requiring high precision is described (*see* p. 121 A).

A Study of Age-Hardening Using the Electron Microscope and Formvar Replicas. D. Harker and M. J. Murphy. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1811: Metals Technology, 1945, vol. 12, June). The mechanism of age-hardening was studied by preparing electron micrographs of Formvar replicas of specimens of copper containing 2% of beryllium, and iron containing 20% of molybdenum. The specimens of the latter alloy were age-hardened at 575°C . for periods of 30 min. to 306 hr. and replicas were made at 8 time-intervals. No important change in microstructure was seen until the ageing treatment exceeded 5 hr. The most that can be said is that the grain boundaries seemed to thicken as time proceeded. After 15 hr. some precipitate appeared. After 50 hr. this precipitate covered all the grains of the specimen. Further ageing caused no apparent changes in the structure. There was no appreciable increase in the hardness until the precipitate began to appear and no further hardening after the precipitation was complete. The technique employed is described in detail and many of the electron micrographs are reproduced.

A Rapid Magnetic Balance. H. Lange and H. Franssen. (Mitteilungen aus dem Kaiser-Wilhelm-Institut, 1942, vol. 24, No. 10, pp. 139-144). The proportion of ferromagnetic material in a specimen can be determined from its specific magnetic saturation. A detailed description is given of a magnetic balance for measuring the magnetic saturation of specimens weighing up to 100 g. With a supply of 1.8 kW. it will produce a field of 56,000 Gauss in a gap 1 mm. wide and 10 mm. in dia.

Hipersil—A Greatly Improved Transformer Iron. T. D. Yensen. (Journal of Applied Physics, 1945, vol. 16, July, pp. 379-385). The development and magnetic properties of "Hipersil," an iron-silicon alloy containing 3-4% of silicon, are discussed. It is made by a combination of hot- and cold-rolling processes followed by a refining annealing process.

Steels for Castings. L. Sanderson. (Engineering and Boiler House Review, 1945, vol. 59, Oct., pp. 271-273). The paper on the properties of heat and corrosion-resisting cast steels is concluded (*see* p. 172 A).

Creep Properties of Some Binary Solid Solutions of Ferrite. C. R. Austin, C. R. St. John, and R. W. Lindsay. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1837: Metals Technology, 1945, vol. 12, Aug.). This paper describes another investigation of a series on the properties of binary iron alloys (*see* Journ. I. and S.I., 1943, No. I., p. 102 A). One microstructural phase, namely ferrite, was isolated and its creep characteristics were studied in both the unalloyed and alloyed conditions. Commercially pure ferrite possesses a relatively low creep resistance at 800°F . Whilst nickel or silicon in solid solution raises the tensile strength and hardness of ferrite at room temperature, they have only a slight effect in raising the resistance to deformation at elevated temperatures. Cobalt is similarly ineffective in raising the creep strength of ferrite. On the other hand, whilst chromium does not markedly increase the strength of ferrite at ordinary temperatures, it definitely

increases the creep strength of ferrite by its presence in solid solution. Manganese and molybdenum in solid solution are ferrite strengtheners and also increase its creep resistance. Increasing the amount of carbon in ferrite progressively increases the creep strength at 800° F., but a similar increase produced by the carbide phase in lamellar distribution does not equal that produced by chromium, manganese or molybdenum in solid solution.

The Status of the Heat-Resisting Constructional Steels. K. Kreitz. (Archiv für das Eisenhüttenwesen, 1942, vol. 15, May, pp. 491-496). Methods of determining the creep strength of steel and the results of creep tests on molybdenum-bearing and molybdenum-free heat-resisting steels are discussed. It is no longer necessary to alloy steels for use at up to 400° C. with molybdenum, as experience has shown certain manganese-silicon, chromium-manganese, and chromium-vanadium steels to have adequate creep strength.

Heat and Corrosion Resistant Steels. R. W. Jones. (Steel Processing. 1945, vol. 31, Aug., pp. 489-493). The advantages of the stainless steels in the manufacture of vessels used in the chemical, petroleum, and other industries, are outlined. The welding properties are discussed in detail. The Carnegie-Illinois Steel Corporation has made available complete data of the properties of all heat- and corrosion-resistant steels.

Application of the Method of Degassification by Electronic Bombardment to the Determination of Gases in Nickel-Chromium Steels. L. Moreau. (Comptes Rendus, 1941, vol. 213, pp. 732-734). The results are presented of determinations of the carbon monoxide, hydrogen and nitrogen in nickel, nickel-chromium alloys and nickel-chromium steels. The determinations were made by the electronic-bombardment method of G. Chaudron and the author (see Journ. I. and S.I., 1935, No. II., p. 532). Alloys containing chromium held comparatively large amounts of nitrogen.

The State of the Diffusion of Hydrogen in Pure Iron at Ordinary Temperatures. G. Chaudron and L. Moreau. (Comptes Rendus, 1941, vol. 213, pp. 790-792). It is shown that there are fundamental differences in the diffusion of hydrogen in pure iron resulting from two methods, (1) electrolytic bombardment, and (2) pickling in acid. In the first case the surface hardness is increased from 90 to about 120 Brinell when 100 c.c. of hydrogen is absorbed per 100 g. of iron; this is caused by a marked distortion of the intergranular network due to the penetration of atomic hydrogen. In the second case the intergranular substance is chemically attacked.

Contribution to the Study of the Penetration of Hydrogen into Monocrystalline and Polycrystalline Iron. A. Portevin, G. Chaudron and L. Moreau. (Comptes Rendus, 1942, vol. 215, pp. 351-353). Samples of iron were made to absorb atomic hydrogen by electrolysis for 8 hr. at -10° C. and the amounts evolved after heating at various temperatures up to 800° C. for different times were determined. The results of fatigue and hardness tests on the samples containing various amounts of hydrogen are presented. It was noted that polycrystalline specimens after heating at 250°-300° C. gave off only about one-third of the hydrogen which they had absorbed, and that nearly all of this was reabsorbed in the intergranular structure on reheating at 900° C. for a very short time. With a monocrystalline structure, on the other hand, the greater part of the hydrogen remained in the intergranular substance after heating at 300° C.

Phenomena Observed When Monocrystalline and Polycrystalline Iron is Impregnated with Hydrogen. A. Portevin, G. Chaudron and L. Moreau. (Comptes Rendus, 1942, vol. 214, pp. 554-555). Specimens of monocrystalline and polycrystalline iron cast under vacuum were treated in hydrogen at 800° C. for increasing periods and the results of microhardness tests on them were related to the amount of hydrogen absorbed. With the

former specimens the hardness increased slowly with the amount of gas absorbed by the intergranular substance, whilst with the latter the hardness decreased rapidly with increasing periods of hydrogen attack. Fatigue tests showed that the number of bends to fracture decreased sharply with increasing absorption of hydrogen by polycrystalline iron whilst it remained constant in the case of monocrystalline iron.

The Effect of Hydrogen on the Elastic Modulus of Iron. G. Chaudron and L. Moreau. (*Comptes Rendus*, 1944, vol. 218, pp. 507-509). The changes in the elastic modulus of Armeo iron during the absorption of hydrogen by electrolysis and during the extraction of hydrogen by ionic bombardment were investigated. The elastic modulus increased steeply with increasing hydrogen absorption whilst the hardness increased slowly. In the second treatment after an intermediate degasification, it increased more slowly whilst the hardness decreased very slightly.

Effect of a Small Quantity of Hydrogen on the Elastic Modulus of Iron and Evidence of a Substructure. G. Chaudron and L. Moreau. (*Comptes Rendus*, 1944, vol. 219, pp. 206-208). From observations made on the manner in which hydrogen increases the elastic modulus of iron, it seems reasonable to assume that a small proportion of the atomic hydrogen finds its way into the intercrystalline material. The authors conclude that the major portion of the hydrogen responsible for the embrittlement gets into the transition zones which separate the mosaic blocks which, according to Darwin, are of the order of magnitude of 10^{-4} cm. This structure is at about the limit of resolution under the microscope. A single crystal of Armeo iron was impregnated with hydrogen by electrolysis at 120 V., absorbing 150 c.c./100 g. At 1000 diameters and after normal polishing no significant structure was observed, but, at over 2000 diameters, a fine-lined structure was noted; this was increasingly evident the slower the rate of hydrogen absorption.

Further Investigations of the Hardening of Molybdenum-Free Heat-Treatable Steels. A. Pomp and A. Krisch. (*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1942, vol. 24, No. 11, pp. 145-158). The study of the properties of molybdenum-free steels (*see* Journ. I. and S.I., 1942, No. I., p. 201 A) was extended to cover a 2.2%-manganese steel, a manganese-chromium-vanadium steel, and a chromium-molybdenum aircraft steel. Extensive tensile and impact tests and hardness surveys were carried out and the results are given in tables and graphs.

The Mechanical Properties of Chromium-Molybdenum and Chromium-Nickel-Molybdenum Heat-Treatable Steels in the Transverse Direction and at Low Temperatures. A. Pomp and A. Krisch. (*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1942, vol. 24, No. 12, pp. 159-166). The properties of chromium-nickel-molybdenum steels in the direction of rolling and transversely were investigated and compared. Generally speaking, the tensile strength and elastic limit were the same in both directions, but there was a marked difference in the elongation, reduction in area and impact values, those in the transverse direction being much lower.

The Suitability of Molybdenum-Free Case-Hardening Steels for Heat-Treatment. A. Pomp and A. Krisch. (*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1942, vol. 24, No. 15, pp. 219-234). The mechanical properties of the German chromium-manganese steels EC 80 and EC 100 after heat-treatment were investigated (*see* Journ. I. and S.I., 1943, No. I., p. 181 A).

German Metallurgy. Some Wartime Specifications in Automobile Construction. (*Automobile*, 1945, vol. 35, Oct., pp. 398-400). The methods adopted in Germany during the war to conserve alloying elements used

for steels for automobile construction are discussed and the composition and hardness of a number of automobile parts are given.

Alloy Steels for Maintenance. J. A. Rosa. (Iron and Steel Engineer, 1945, vol. 22, Sept., pp. 37-45). Factors affecting the selection of alloy steels for maintenance in steelworks are discussed and a comprehensive table is presented of names of parts with the recommended type of steel and its heat-treatment.

A.I.D. Test House, Harefield. (Engineer, 1945, vol. 180, Nov. 2, pp. 342-344; Nov. 9, pp. 361-362). An illustrated description is given of the organization and equipment at the new testing establishment of the Aeronautical Inspection Department of the Ministry of Aircraft Production at Harefield, Middlesex.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 172 A-173 A)

A Photoelectric Exposure Meter for Metallography. A. J. Brunner. (Metals and Alloys, 1945, vol. 22, Aug., pp. 416-417). An exposure meter for photomicroscopy is described. It incorporates a photo-electric cell mounted in a cardboard slide which fits into the camera in place of the ground glass.

The Technique of Macrography. (Chemical Age, 1945, vol. 53, Sept. 1, pp. 195-197; Oct. 6, pp. 316-318; Nov. 3, pp. 411-413). The methods and apparatus employed in macrography are outlined the subject being dealt with in three sections, namely, preparation of the specimen by macro-etching, examination of cast iron and of alloys, and photographic apparatus and procedure.

Investigations on the Relaxation by Crystal Recovery and Recrystallization of Critically Cold-Worked and Annealed Low-Carbon Steel. A. Pomp and G. Niebch. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1942, vol. 24, No. 5, pp. 47-59). An English translation of this paper has appeared in Sheet Metal Industries, 1944, vol. 19, Mar., pp. 428-433 and Apr., pp. 627-628 (see Journ. I. and S.I., 1944, No. II., p. 59 A).

Effect of Variables on the Recrystallization of Silicon Ferrite in Terms of Rates of Nucleation and Growth. J. K. Stanley. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1840: Metals Technology, 1945, vol. 12, Aug.). The present paper is a continuation of the study of recrystallization of 1% silicon-ferrite (see Journ. I. and S.I., 1942, No. II., p. 223 A). The effects of deformation, temperature, grain size, composition, and recovery on the rates of nucleation and growth were studied. Increasing deformation increases both these rates. A fine-grained material recrystallizes more rapidly than a coarse-grained material. The addition of silicon to iron decreases both the above rates. Specimens were elongated 4% and annealed at 350° C. for 25 hr.; they were then recrystallized at 800° C. with material similarly elongated but not "recovered." The low-temperature treatment caused a very slight increase in the rate of recrystallization.

The Liquidus-Solidus Temperatures and Emissivities of Some Commercial Heat-Resistant Alloys. J. T. Gow, A. de S. Brasunas and O. E. Harder. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1838: Metals Technology, 1945, vol. 12, Aug.). The techniques employed to determine the liquidus and solidus temperatures of two heat-resisting iron alloys containing 26% and 16% of chromium and

12% and 36% of nickel respectively, are described and the results obtained discussed.

The Constitutional Diagram for Chromium-Nickel Steels Containing Nitrogen. H. Krainer and M. Nowak-Leoville. (Archiv für das Eisenhüttenwesen, 1942, vol. 15, May, pp. 507-513). Metallographic and X-ray investigations of the structure of 39 chromium-nickel alloys treated with nitrogen were carried out and constitutional diagrams were constructed from the data obtained. The hardness, notched-bar impact strength and magnetic saturation of the alloys were also determined. The composition of the alloys was in the range 10-30% of chromium, 3-30% of nickel and 0.04-0.50% of nitrogen. The addition of nitrogen does not introduce any new phase in the chromium-nickel alloys, but it moves the stable range of the γ -phase towards lower nickel compositions. With the alloys low in nickel the brittle σ -phase is moved by the nitrogen additions towards higher chromium compositions.

CORROSION OF IRON AND STEEL

(Continued from pp. 149 A-151 A)

Durability of Light Weight Steel Construction. Part III.—Protection of Steel Surfaces from Atmospheric Corrosion. J. H. Cissel and W. E. Quinsey. (Department of Engineering Research of the University of Michigan, 1942, Bulletin No. 30). This booklet consists of a list of 1467 abstracts on the corrosion and protection of steel; it covers the period 1877-1942 in chronological order and is provided with subject and author indices.

Marine Corrosion and Erosion. J. W. Donaldson. (Metal Treatment, 1945, vol. 12, Autumn Issue, pp. 159-170). Results obtained during the last five years by corrosion, erosion and cavitation tests in Great Britain and the United States are reviewed.

Cast Iron in the Chemical and Process Industries. F. L. LaQue. (Gray Iron Founders' Society, 1945, Pamphlet). Applications of cast iron in the chemical industry are discussed and a table extending over 20 pages is presented which contains data from laboratory and full-scale tests on the resistance of cast irons to attack by acids, alkalies and many chemical solutions.

Electro-Tin.—Protective Value As an Undercoating. S. Wernick. (Electrodepositors' Technical Society: Metal Industry, 1945, vol. 67, Sept. 28, pp. 202-204; Oct. 12, pp. 235-236). See p. 23 A.

Symposium on Corrosion Inhibitors. (American Chemical Society: Industrial and Engineering Chemistry, Industrial Edition, 1945, vol. 37, Aug., pp. 702-749). A symposium was held recently in New York by the Divisions of Industrial and Engineering Chemistry and of Water Sewage and Sanitation Chemistry, on "Inhibitors for Control of Scale and Corrosion in Water" at which the following papers were read:

Use of Soluble Inhibitors. U. R. Evans.

Zinc, Manganese, and Chromium Salts as Corrosion Inhibitors.

R. S. Thornhill.

Threshold Treatment of Water Systems. G. B. Hatch and O. Rice.

Protection of Small Water Systems from Corrosion. W. Stericker.

Galvanic Corrosion of Steel Coupled to Nickel. H. R. Copson.

Scale and Corrosion Control in Portable Water Supplies at Army Posts. R. T. Hanlon, A. J. Steffen, G. A. Rohlich, and L. H. Kessler.

Inhibitors of Corrosion of Aluminium. G. G. Eldredge and R. B. Mears.

Chromate Corrosion Inhibitors in Bimetallic Systems. M. Darrin.

Sodium Nitrite as Corrosion Inhibitor for Water. A. Wachter. (Industrial and Engineering Chemistry, Industrial Edition, 1945, vol. 37, Aug., pp. 749-751). Sodium nitrite is a corrosion inhibitor for water and can, under many conditions, suppress the corrosion of steel. It can completely prevent attack on steel in sodium-chloride solutions and in aqueous alcohol solutions. It is also effective on steel covered with rust scale. Corrosion of many ferrous and non-ferrous metals is either inhibited or not adversely affected by the presence of sodium nitrite. The concentrations needed for pronounced inhibition vary with the severity of the conditions, the pH value, and the composition of the water.

Corrosion Control with Threshold Treatment. G. B. Hatch and O. Rice. (Industrial and Engineering Chemistry, Industrial Edition, 1945, vol. 37, Aug., pp. 752-759). The rate of formation of protective films on steel and metal surfaces in threshold-treated waters is a function of the rate of supply of the glassy phosphate to these surfaces and is dependent on the type and velocity of flow. Two types of batch tests, designed to provide motion of the liquid around the metal, were found to yield results amenable to the same interpretations as those from continuous flow tests. By means of these batch tests the effects of intermittent motion, temperature, and of couples on the inhibitive action of the glassy phosphate were determined. Inhibitors were tested in brines and tap water.

Synthetics and Engineered Corrosion Control. D. F. Siddall. (Monthly Review of the American Electroplaters' Society, 1945, vol. 32, Apr., pp. 331-336). The theory of corrosion and corrosion prevention is discussed and the manufacture of synthetic materials from organic substances to act as protective linings is explained.

Statistical Methods in Deciding the Efficacy of a Modification in Technical Procedure: The Use of the *t*-Test to Chemists and Engineers. U. R. Evans. (Chemistry and Industry, 1945, Apr. 7, pp. 106-109). Statistical methods of comparing the results of two sets of tests for evaluating the efficacy of a device or technical procedure are discussed. An orthodox and an unorthodox method of employing the *t*-function are explained (see Journ. I. and S.I., 1944, No. I., p. 70 A).

The Laws of Expanding Circles and Spheres in Relation to the Lateral Growth of Surface Films and the Grain-Size of Metals. U. R. Evans. (Transactions of the Faraday Society, 1945, vol. 41, July, pp. 365-374). Problems connected with the properties of expanding circles and spheres are met with in considering the covering of a metallic surface by films or layers of a corrosion product, the formation of which starts at nuclei and spreads outwards. A method of solution based on the "Additivity of Expectation" is explained in this paper by considering eleven simple cases.

ANALYSIS

(Continued from pp. 151 A-152 A)

Spectro-Chemical Analysis. G. S. Smith. (Metal Industry, 1945, vol. 67, Oct. 12, pp. 226-228). The spectro-chemical methods of analysis used in Russia are described. These methods are the results of developments in technique evolved with insufficient instruments. Semi-quantitative analysis is carried out extensively by means of the Steelascope which is made in Russia.

Methods that Offer New Tools for Process Control. (Chemical and Metallurgical Engineering, 1945, vol. 52, July, pp. 119-126). Brief descriptions are given of modern research techniques and instruments which are now being applied in industry for the control of chemical and

metallurgical processes. These techniques include emission and absorption spectrography, infra-red spectroscopy, the use of the mass spectrometer, X-ray diffraction analysis and electron microscopy.

An Application of Spectrographic Methods to Chemical Concentrations of Trace Elements in Iron and Steel Analysis. R. A. Wolfe and R. G. Fowler. (Journal of the Optical Society of America, 1945, vol. 35, Jan., pp. 86-91). Combined spectrographic-chemical techniques for obtaining acceptable determinations of elements present in iron alloys in amounts below the usual limits of detection by either method alone are described.

The Application of Spectrochemical Analysis in the Steel Mill. P. R. Irish. (Journal of the Optical Society of America, 1945, vol. 35, Mar., pp. 226-233). A description is given of the methods which have been developed by the Bethlehem Steel Company in their spectrographical laboratory where as many as 8000 separate determinations are made in a week.

Dilution Factor in Spectrochemical Analysis. C. B. Post, D. G. Schoff-stall and G. Gurley. (Industrial and Engineering Chemistry, Analytical Edition, 1945, vol. 17, July, pp. 412-416). The applicability of the atomic dilution factor in spectrochemical analysis has been studied, applying two methods for exciting the spectra of ferrous alloys, one being that described by M. F. Hasler, C. E. Harvey and H. W. Dietert (Journ. I. and S.I., 1943, No. II., p. 59 A) and the other using chill-cast metal electrodes in a condensed spark circuit. Dilution may be expressed in terms of atomic per cent dilution, permitting economical and accurate analysis of a wide range of alloys without recourse to a series of standard samples or a number of calibration curves for each alloy.

A Comparator for Spectrographic Analysis. K. B. Mather. (Journal of Scientific Instruments, 1945, vol. 22, Aug. pp. 151-153). A description is given of a spectro-comparator designed for 10-in. negatives. In layout the instrument resembles the Judd Lewis comparator, but several modifications have been introduced.

Non-Destructive Spectrographic Sampling. S. L. Widrig and F. W. Lutz. (Metal Progress, 1945, vol. 48, Aug., pp. 276-279). It is not always convenient to remove samples $\frac{1}{4}$ in. in dia. from a part for spectrographic analysis, so that a new technique was developed which consists of removing a chip or fragment from the part to be analysed and welding it on the end of a mild steel pin. The chip is then ground to the same diameter as the pin and a cone is ground in the end of it. The air-gap interrupter used in place of the usual synchronous interrupter to increase the number of discharges per cycle is also described.

Application of Micro Combustion Technique to Metallurgical Analysis. G. Ingram. (Metallurgia, 1945, vol. 32, July, pp. 137-140; Sept., pp. 237-239). The problems associated with the application of micro-combustion technique to the determination of carbon and sulphur in steels are discussed. The apparatus required is described and a method for determining sulphur in 10 mg. samples when present in amounts above 0.01% is given.

Application of Colorimetry to Analysis of Corrosion-Resistant Steels. S. Weinberg, K. L. Proctor and O. Milner. (Industrial and Engineering Chemistry, 1945, vol. 17, July, pp. 419-422). A rapid method of determining boron, in amounts ranging from 0.001% to 0.005%, in corrosion-resistant steels is described. The method is satisfactory for routine purposes in highly coloured solutions where the boron cannot be estimated directly.

Application of Colorimetry to the Analysis of Corrosion-Resistant Steels. L. G. Bricker and K. L. Proctor. (Industrial and Engineering Chemistry, Analytical Edition, 1945, vol. 17, Aug., pp. 511-512). A procedure for determining small amounts of lead in corrosion-resistant steels is suggested.

The method is rapid and the precision is greater than in any other procedure investigated.

Colorimetric Determination of Nickel and Chromium in a Combined Form of Analysis. W. B. Sobers. (American Foundryman, 1945, vol. 8, Aug., pp. 45-48). Improved colorimetric methods of determining small amounts of nickel and chromium in steel are described. These are modifications of the method described by W. M. Murray and S. E. Q. Ashley (see Journ. I. and S.I., 1938, No. I., p. 360 A).

Colorimetric Estimation of Aluminum in Aluminum Steel. C. H. Craft and G. R. Makepiece. (Industrial and Engineering Chemistry, Analytical Edition, 1945, vol. 17, Apr., pp. 206-210). A method is presented for the colorimetric estimation of acid-soluble aluminium in steel in the range of 0.04% to 1.5% by means of ammonium aurintricarboxylate.

Rapid Spot Tests for Nickel in Steel. E. R. Vance and H. S. Gonser. (Iron Age, 1945, vol. 156, Sept. 13, p. 54-0). A rapid test for detecting the presence of nickel in steels and for estimating the amount is described. A drop of a mixture of nitric and phosphoric acids is placed on a cleaned area of the steel for about 10 sec.; it is then absorbed by filter paper; when two drops of dimethyl-glyoxime solution are applied to the spot on the paper it turns pink or red, the exact shade depending on the nickel content.

A Rapid Volumetric Method for the Determination of Silicon in Iron and Steel. F. Kordon. (Iron and Steel Institute, 1945, Translation Series, No. 255). An English translation is presented of a paper which appeared in Archiv für das Eisenhüttenwesen, 1945, vol. 18, Jan.-Feb., pp. 139-146 (see p. 47 A).

A Rapid Method for Determination of Silica in Iron Ore and a Spectrophotometric Method for Phosphorus. C. C. Hawes. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1794: Metals Technology, 1945, vol. 12, Aug.). A method of determining silica in iron ore is described. Ten parts of sodium carbonate were ground to a fine powder together with seven parts of zinc oxide. About 5 g. of the mixture were mixed intimately with 0.5 g. of the ore and heated for 20 min. in a platinum crucible. No fusion took place, but a grey button was formed which was easily removed from the crucible. The button, containing all the transformed silicates, dissolved very easily in dilute hydrochloric acid. Perchloric acid was used to dehydrate the silica.

The filtrate from the silica contained all the phosphorus and was thus an excellent medium for determining the total phosphorus. A spectrophotometric method for determining phosphorus based on the precipitation of yellow ammonium phosphomolybdate is also described.

The Determination of Nitrogen in Nitrided Iron by the Method of Ionic Bombardment. L. Moreau and G. Chaudron. (Comptes Rendus, 1943, vol. 217, pp. 397-399). A method is described for the determination of nitrogen in iron which had been heated at 650° C. in ammonia. The nitrogen in the form of nitrides was determined by ionic bombardment at low temperature with subsequent heating under vacuum at 900-950° C. The specimens were next re-impregnated with hydrogen by electrolysis and the nitrogen in solution in the iron could then be extracted and determined.

The Influence of Heat-Treatment on the Determination of Nitrogen in Alloy Steels and Pig Iron. C. Holthaus and W. Holtmann. (Iron and Steel Institute, 1945, Translation Series, No. 251). An English translation is presented of a paper which appeared in Archiv für das Eisenhüttenwesen, 1944, vol. 17, May-June, pp. 247-260 (see Journ. I. and S.I., 1945, No. I., p. 160 A).

On the Spectrochemical Determination of Vanadium in Iron Ores and Slags. A. Kvalheim. (Norsk Geologisk Tidsskrift, 1941, vol. 21, No. 4,

pp. 245-267). Two spectrochemical methods for determining vanadium in iron ores and in slags are described. By the first method the intensity of the vanadium lines 3185 and 3056 is compared with the intensity of the iron lines 3205 and 3055 produced by the iron content of the sample itself. In the second method 1 part of Cr_2O_3 is added for comparison to 10 parts of the standards and samples. A method for determining vanadium and chromium in slags spectrochemically by two spectra is also described.

The Rapid Determination of the Iron-Oxide Content of Slags. P. Borel. (*Revue de Métallurgie, Mémoires*, 1941, vol. 38, Jan., pp. 30-31). The method, described by the author, is used for slags the composition of which permits rapid attack by hydrochloric acid. It is based on the colour of the ferric salts in the presence of potassium thiocyanate. The test takes about 3 min. and allows an estimate to be made of the approximate content of FeO from the intensity of the red colouring.

The Rapid Chemical Determination of Iron, Manganese, Silica, and Lime in Basic Open-Hearth Slags to Control the Melting Process. E. Stengel. (Iron and Steel Institute, 1945, Translation Series, No. 243). An English translation is presented of a paper which appeared in *Stahl und Eisen*, 1944, vol. 64, Dec. 21, pp. 802-806 (see *Journ. I. and S.I.*, 1945, No. I., p. 161 A).

Magnetic Stirring in the Analytical Electrodeposition of Metals. H. W. Webb. (*Analyst*, 1945, vol. 70, Aug., pp. 301-304). In assay laboratories increased interest is now shown in the rapid deposition of metals by the electrolysis of stirred solutions. The merits of stirring solutions by mechanical and by magnetic means are compared. Experiments using magnetically stirred electrolytes are described and the suggestion that permanent magnets might be substituted for electro-magnets is made.

Polarographic Determination of Iron and Zinc in Phosphate Coatings. J. Knanishu and T. Rice. (*Industrial and Engineering Chemistry, Analytical Edition*, 1945, vol. 17, July, pp. 444-446). A polarographic method for the simultaneous determinations of iron and zinc in commercial phosphate coatings is described. The complete analysis can be made in less than 1 hr.

Colorimetric Methods as Applied to the Analysis of Electroplating Baths. I. The Determination of Lead. II. The Determination of Traces of Nickel. III. Chromium. IV. The Determination of Iron. D. G. Foulke. (*Monthly Review of the American Electroplater's Society*, 1944, vol. 31, Dec., pp. 1103-1108; 1945, vol. 32, Jan., pp. 7-10; Feb., pp. 149-152; Mar., pp. 249-251).

Methods for the Determination of Carbon and Hydrogen in Coal and their Practical Utility. J. H. Jones. (*Institute of Fuel War Time Bulletin*, 1945, Oct., p. 37). A note on the Fenton method for the determination of carbon and hydrogen is given.

BIBLIOGRAPHY

(Continued from p. 126 A)

AMERICAN IRON AND STEEL INSTITUTE. "*Iron and Steel Industry. Position, Descriptions and Classifications.*" No. 23. General Office Administration. May, 1945. New York 1, N.Y. 1945: The Institute.

BABCOCK AND WILCOX, LTD. "*Water Treatment Manual.*" 8vo, pp. 97. London: Babcock and Wilcox, Ltd.

BARR, W., and A. J. K. HONEYMAN. "*Steel and Its Practical Applications.*" Second ed. 8vo, pp. xii + 156. Illustrated. London and Glasgow, 1945: Blackie and Son, Ltd. (Price 8s. 6d.),

- BRITISH STANDARDS INSTITUTION. B.S. 1224: 1945. "*Electroplated Coatings of Nickel and Chromium on Steel and Brass.*" 8vo, pp. 23. Illustrated. London, 1945: The Institution. (Price 2s.).
- BRITISH STANDARDS INSTITUTION. B.S. 1228: 1945. "*Door Bolts. Iron, Steel and Non-Ferrous.*" 8vo, pp. 18. Illustrated. (Price 2s.).
- BRITISH STANDARDS INSTITUTION. B.S. 1256: 1945. "*Malleable Cast Iron and Cast Copper Alloy Pipe Fittings for Steam, Water and Gas.*" Screwed B.S.P. Taper Male Thread and Parallel Female Thread. 8vo, pp. 53. Illustrated. (Price 3s. 6d.).
- BRITISH STANDARDS INSTITUTION. B.S. 1264: 1945. "*Methods of Test for Transport Gas Producer Fuels.*" 8vo, pp. 26. Illustrated. (Price 2s.).
- BRITISH STANDARDS INSTITUTION. B.S. 1271: 1945. "*Proof Test for Creep Quality of Carbon Steel Plate of Boiler Plate Quality.*" 8vo, pp. 3. (Price 1s.).
- BRITISH STANDARDS INSTITUTION. BS/STA 25. "*Services Specification for High Silicon Iron Castings.*" La. 8vo, pp. 2. (Price 6d.).
- ECKMAN, D. P. "*Principles of Industrial Process Control.*" 8vo, pp. x + 237. Illustrated. New York, 1945: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd. (Price \$3.50).
- EVANS, E. A. "*Lubricating and Allied Oils.*" London: Chapman and Hall, Ltd. (Price 15s.).
- HOUNSFIELD, L. H. "*Commercial Testing. Part 1. Notched-Bar Testing.*" 8vo, pp. 42. Croydon, 1945: The Author. (Price 3s. 6d.).
- MANTELL, C. L., and C. HARDY. "*Calcium Metallurgy and Technology.*" Pp. 148. New York, 1945: Reinhold Publishing Corporation. (Price \$3.50).
- MIGEOT, J., and A. MAHY. "*Cours de Métallurgie T. I. Chauffage industriel, combustibles, matières premières.*" Pp. 115. Bruxelles: J. Rowat. (Price 12 francs).
- MINISTRY OF LABOUR AND NATIONAL SERVICE. "*Memorandum on Carbon Monoxide Poisoning.*" (Revised Ed.). Form 827, May, 1945. 8vo, pp. 32. Illustrated. London, 1945: H.M. Stationery Office. (Price 6d.). (See p. 23 A).
- MUHLENBRUCH, C. W. "*Testing of Engineering Materials.*" 8vo, pp. 200. Illustrated. New York: D. Van Nostrand Co., Inc. (Price \$2.75).
- NATIONAL RESEARCH COUNCIL. "*Chemistry of Coal Utilisation.*" Prepared by the Committee on Chemical Utilisation of Coal, Division of Chemistry and Chemical Technology, National Research Council. In 2 Volumes. Pp. 2078. Illustrated. New York: John Wiley and Sons, Inc. (Price \$20.00).
- QUASI-ARC CO., LTD. "*Quasi-Arc Welding Manual.*" First Ed. August, 1945. 8vo, pp. 168. Illustrated. Bilston, 1945: The Quasi-Arc Co., Ltd. (Price 3s. 6d.).
- ROLFE, R. T. "*A Dictionary of Metallography.*" 8vo, pp. viii + 243. London, 1945: Chapman and Hall, Ltd. (Price 15s.).
- SHEPPARD, R. "*Cast Iron in Building.*" With an Introduction by J. G. Pearce. 8vo, pp. 98. Illustrated. London, 1945: George Allen and Unwin, Ltd. (Price 7s. 6d.).

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